Strangeness Production in pp, p-Pb and Pb-Pb collisions measured by ALICE at the LHC

UNICAMP ALICE

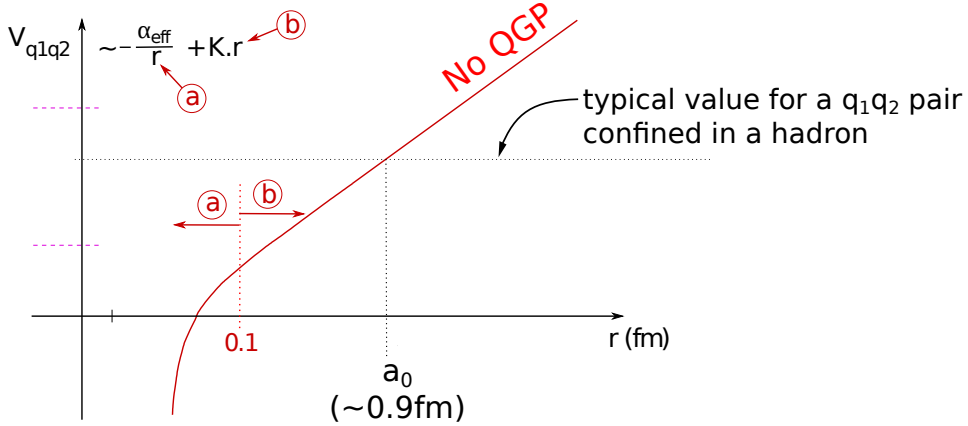
D.D. Chinellato for the ALICE Collaboration

XXV Reunião de Trabalho Sobre Interações Hadrônicas

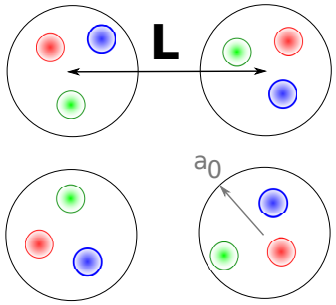
Outline

- **1. Introduction**
  - Physics Motivation: the QGP and what to measure
  - The ALICE Experiment
  - The K^0_s, Λ, Ξ, Ω measurements
- **2. Results in proton-proton collisions**
- **3. Results in Pb-Pb collisions**
- **4. Results in p-Pb collisions**
- **5. Conclusions and Prospects**

The Quark-Gluon Plasma



scenario 1: confinement



L: Inter-Hadronic Distance (~1.8fm)
a_0: Nuclear Radius (~0.9fm)
ρ_0: typical nuclear density (~0.17 nucleon/fm^3)

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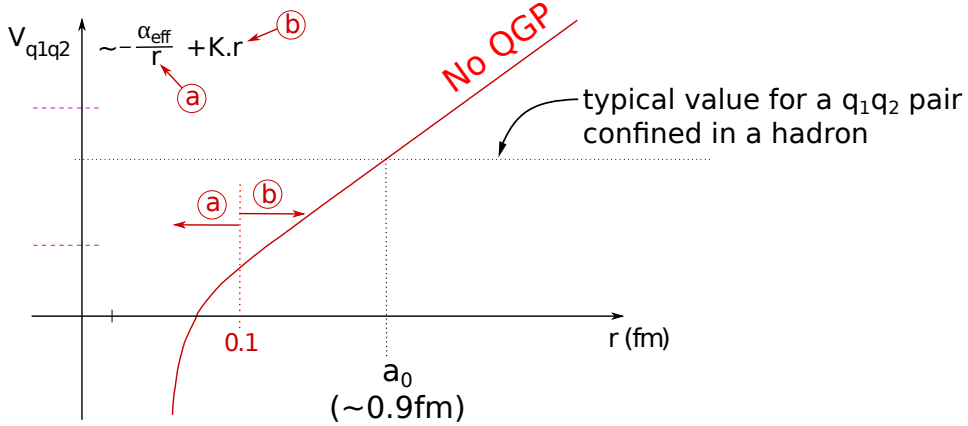

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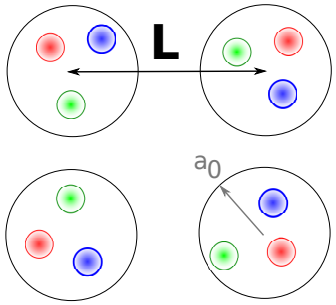

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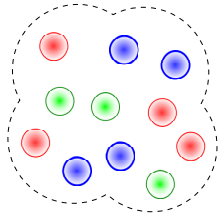
scenario 2: deconfinement



Critical Limit: L ~a_0

$\rho_{eff} \sim (1.8/0.9)^3 \rho_0 = \sim 8\rho_0$

$8\rho_0$ = 1.36 nucleon/fm^3 ~ 1.2GeV/fm^3

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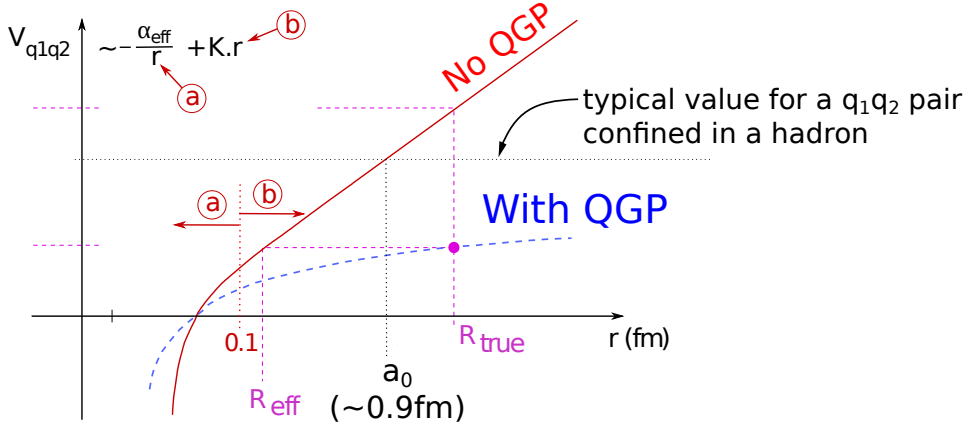

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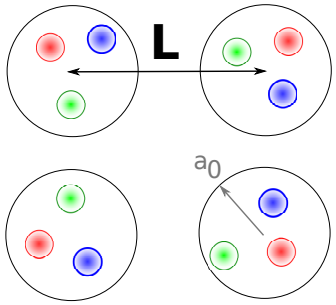

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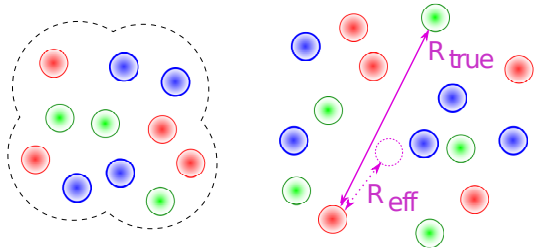

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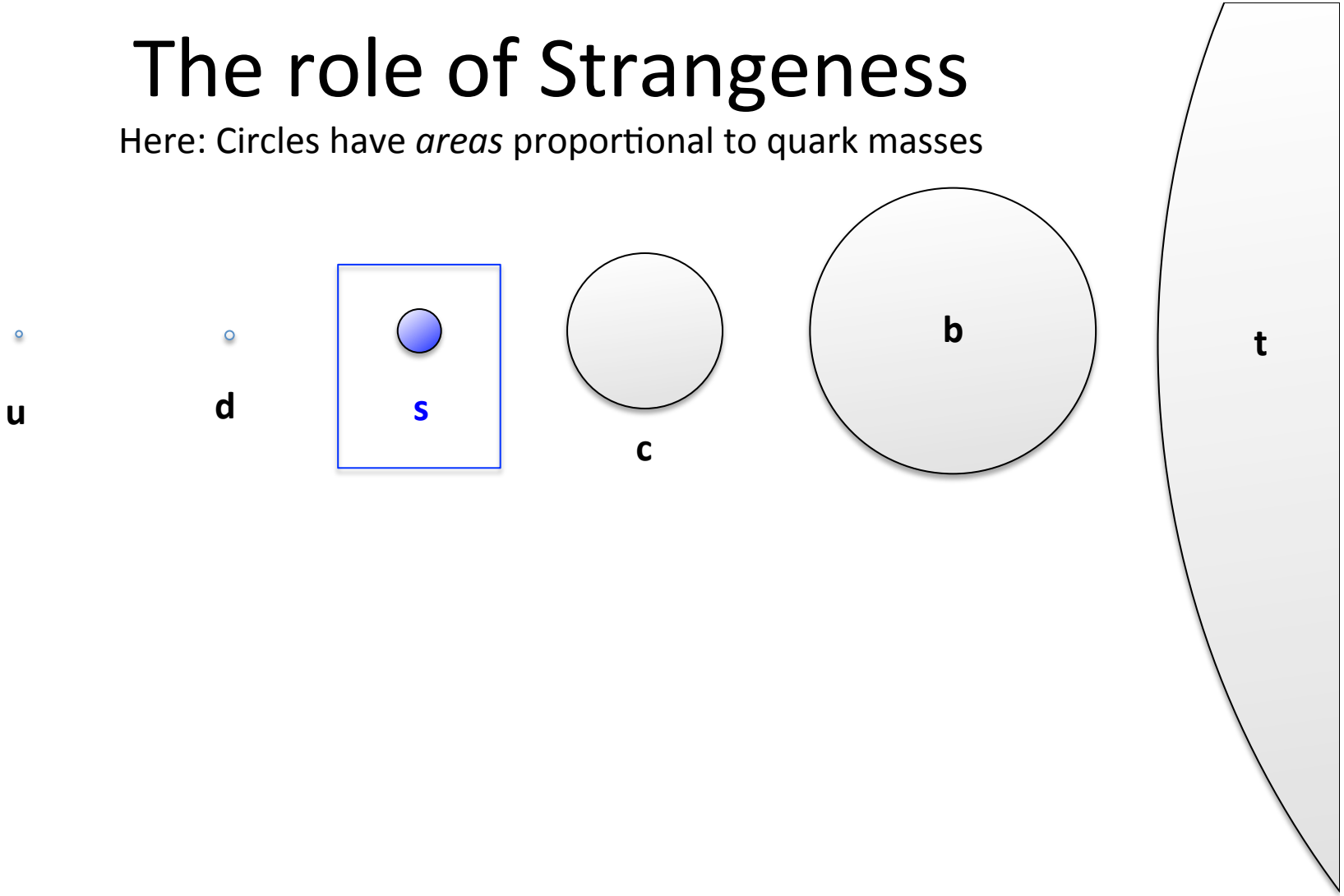
The role of Strangeness

Here: Circles have *areas* proportional to quark masses



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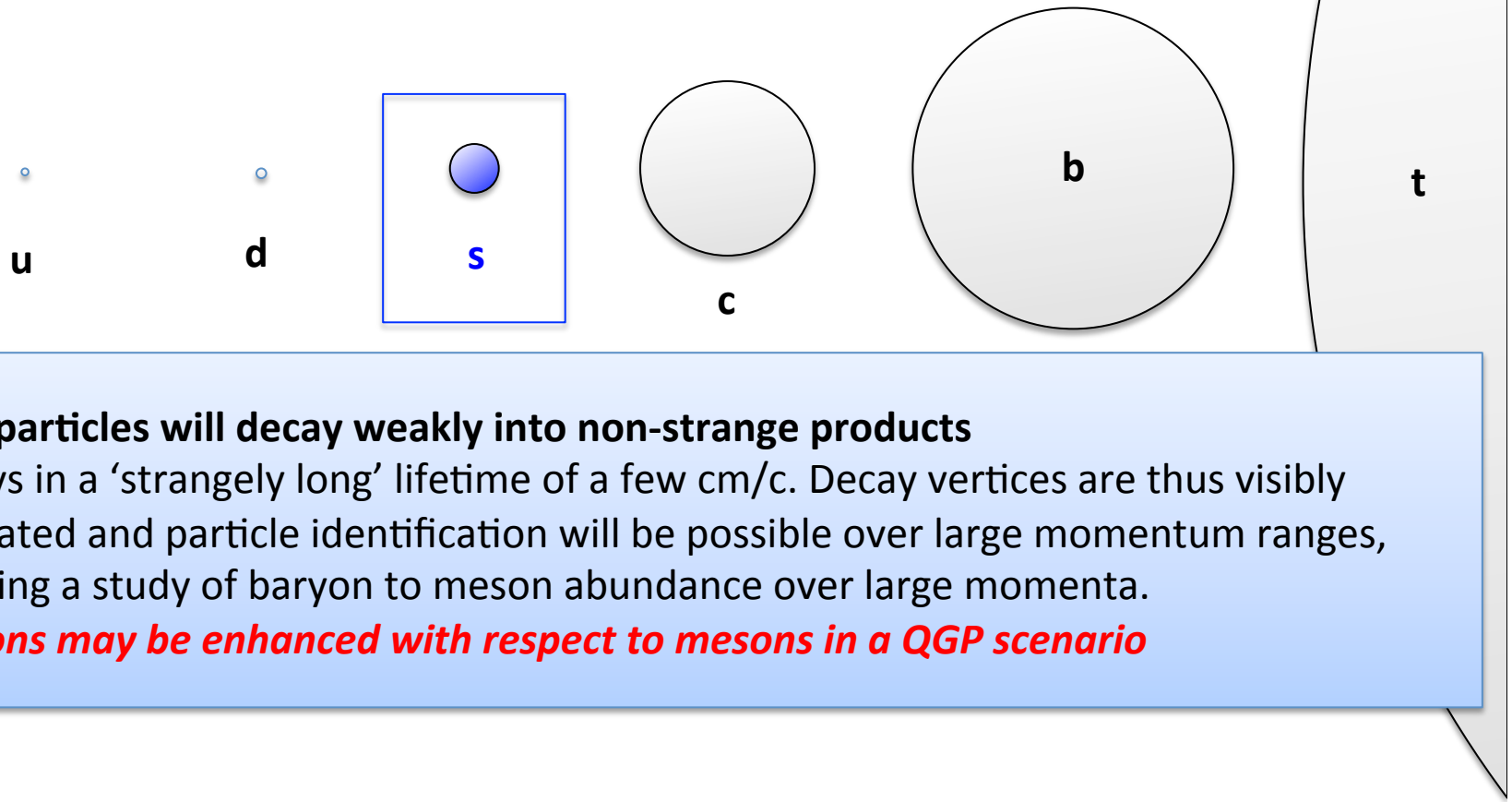

Strange particles will decay weakly into non-strange products

- Decays in a 'strangely long' lifetime of a few cm/c. Decay vertices are thus visibly separated and particle identification will be possible over large momentum ranges, enabling a study of baryon to meson abundance over large momenta.
- ***Baryons may be enhanced with respect to mesons in a QGP scenario***

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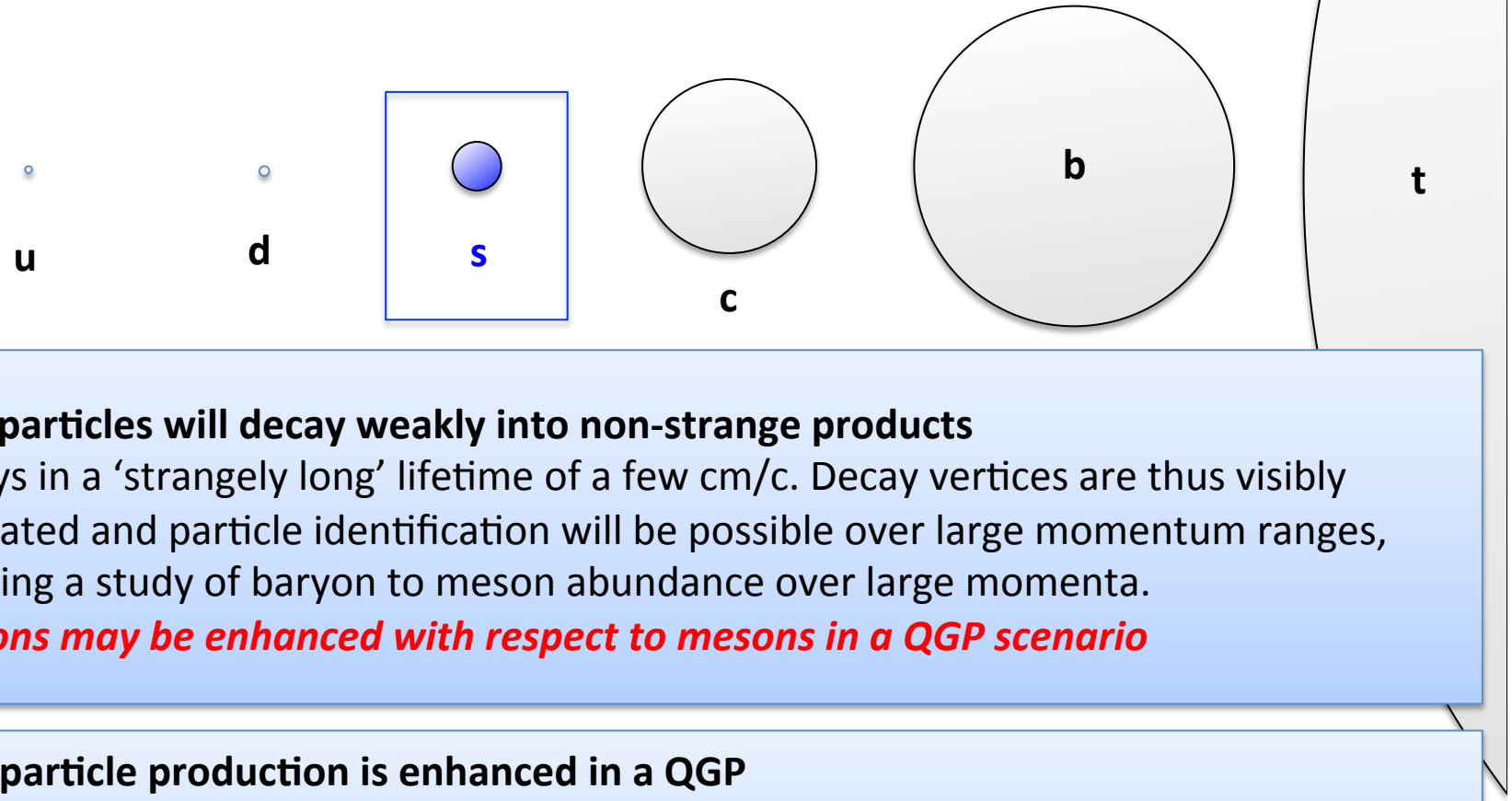

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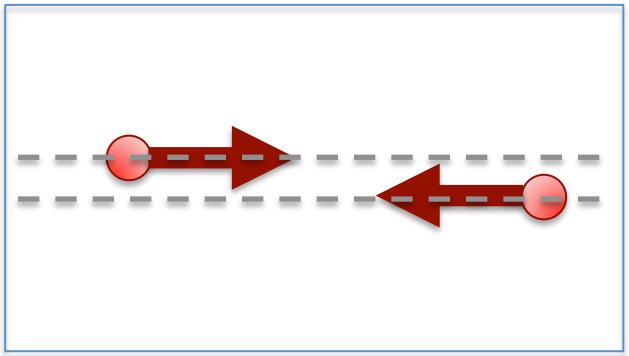
- ***Baryons may be enhanced with respect to mesons in a QGP scenario***

Strange particle production is enhanced in a QGP

- It is believed that *gluon fusion* occurs in the QGP as an $s\bar{s}$ creation mechanism
- *Pauli Blocking* may lead to more $s\bar{s}$ pairs, as *u* and *d* quarks fill up all available states
- Thus, ***more strangeness may be produced in a QGP*** if compared to the non-QGP scenario.

What to measure?



The proton-proton (pp) colliding system

- Elementary hadronic system, few prod. particles
- No collectivity or deconfinement expected
- Suitable as benchmark, 'hadron gas' scenario
- pQCD-inspired models such as PYTHIA: tested!

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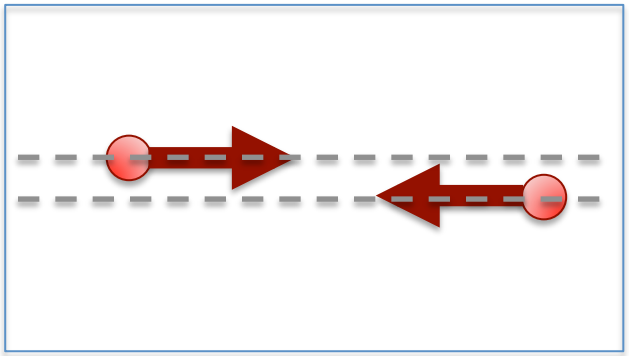

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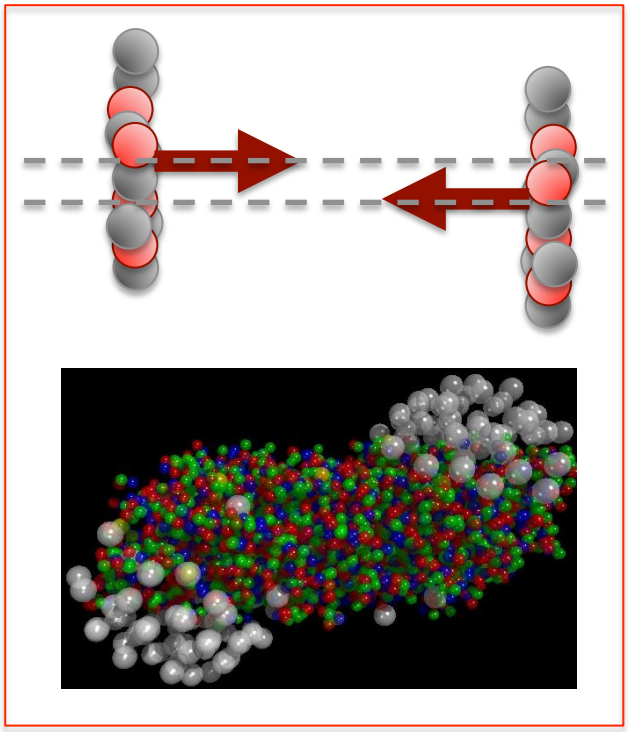

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- Large system (nuclear volume)
- Deconfinement/QGP scenario, hot nuclear matter
- *Collectivity*: Signatures such as: Particle flow, etc…

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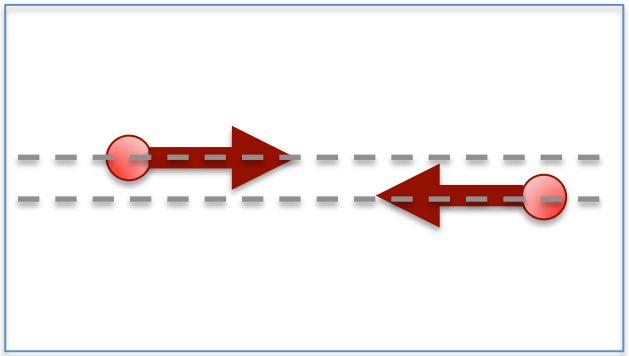

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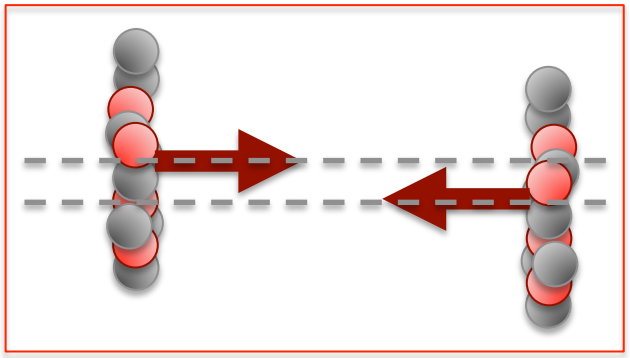

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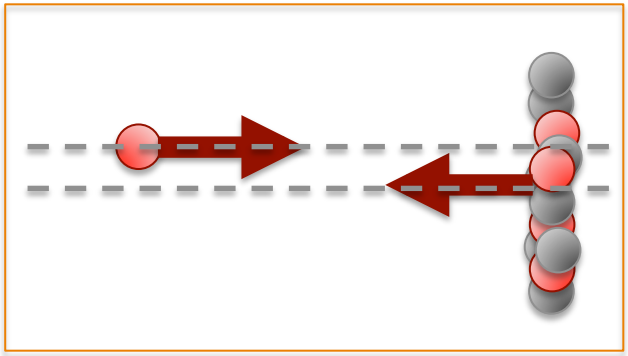
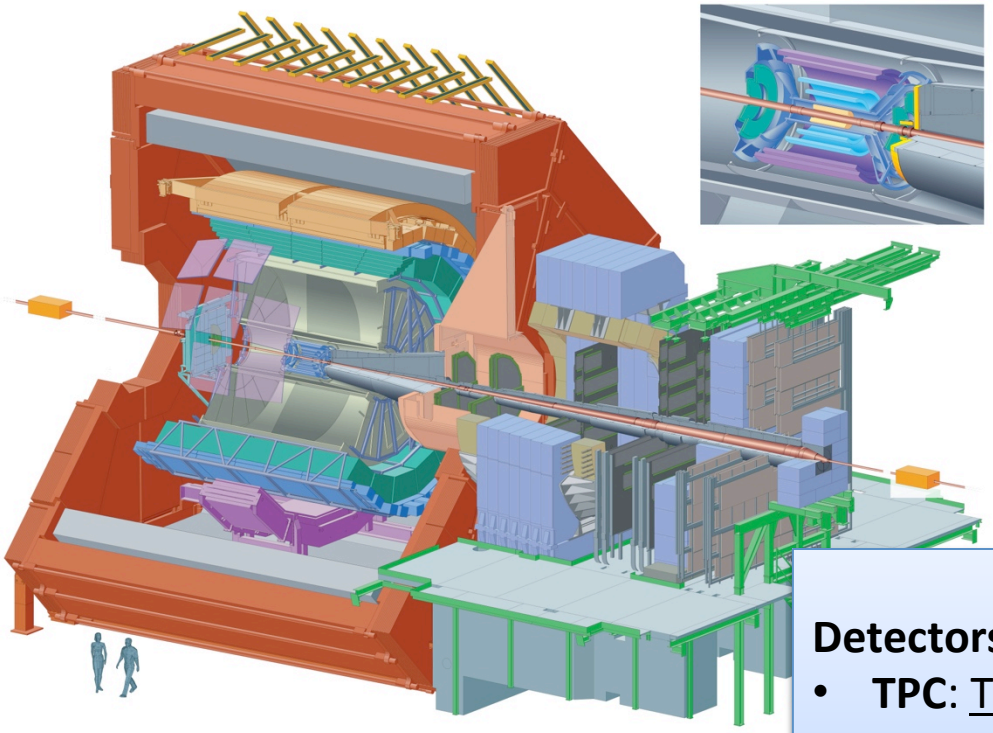


The proton-lead (p-Pb) colliding system

- Intermediate system: what about collectivity?
- May potentially be well suited to understand the effects in the transition from a hadron gas (pp) to a QGP regime (Pb-Pb) and interactions with cold nuclear matter

The ALICE Experiment at the LHC



Collaboration:
1275 members
135 institutes
37 countries

Specialty: Nuclear Collisions
Specificity: Particle Identification

Detectors Used In this study:

- **TPC**: Tracking, Vertexing, PID (dE/dx)
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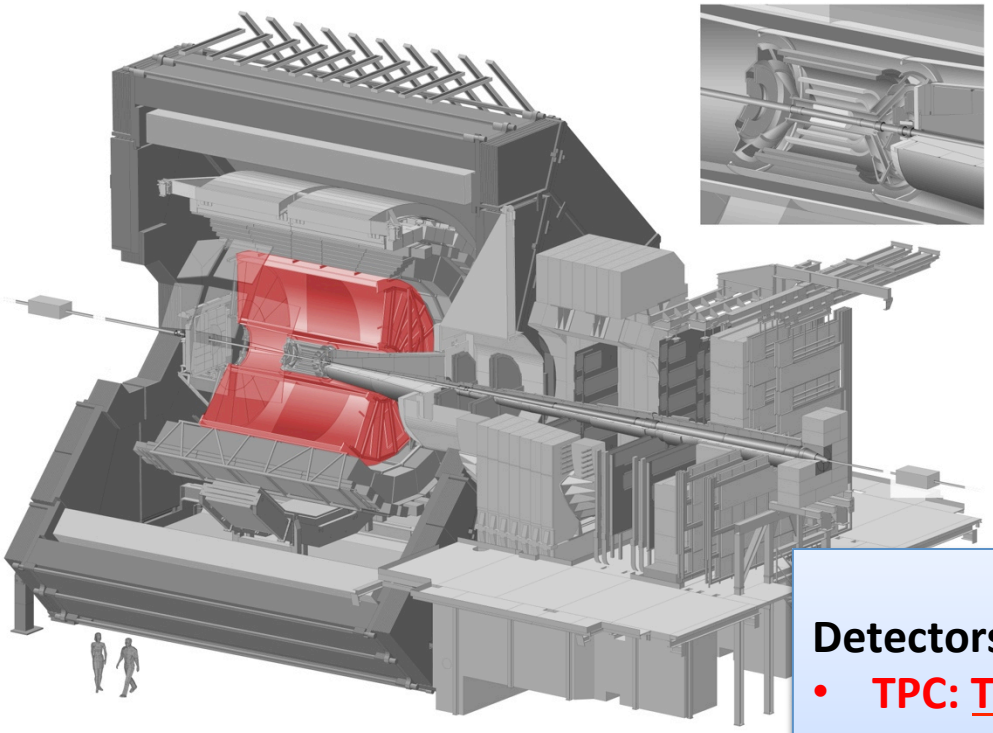

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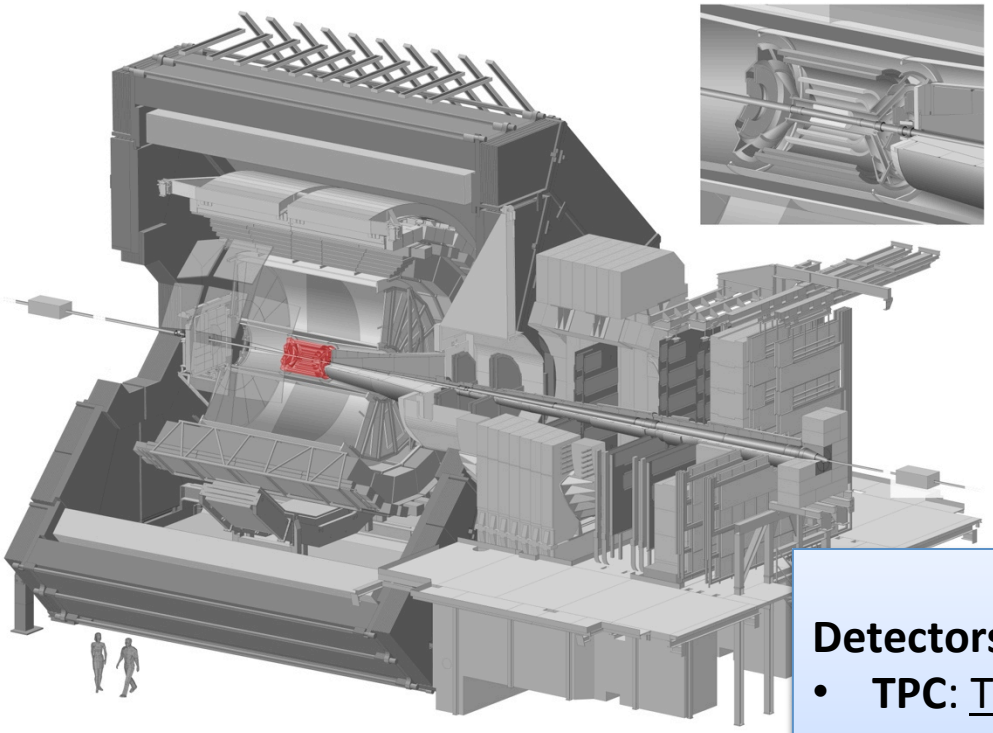

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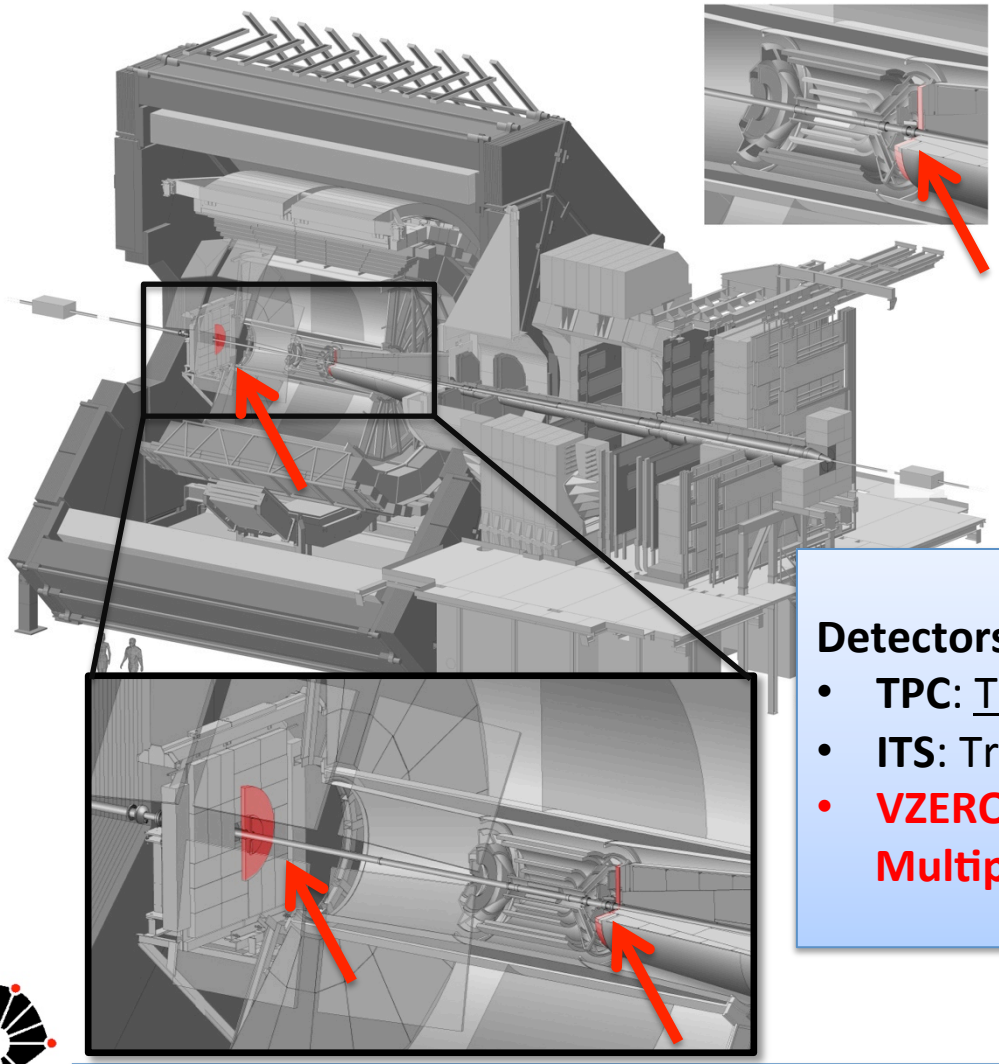

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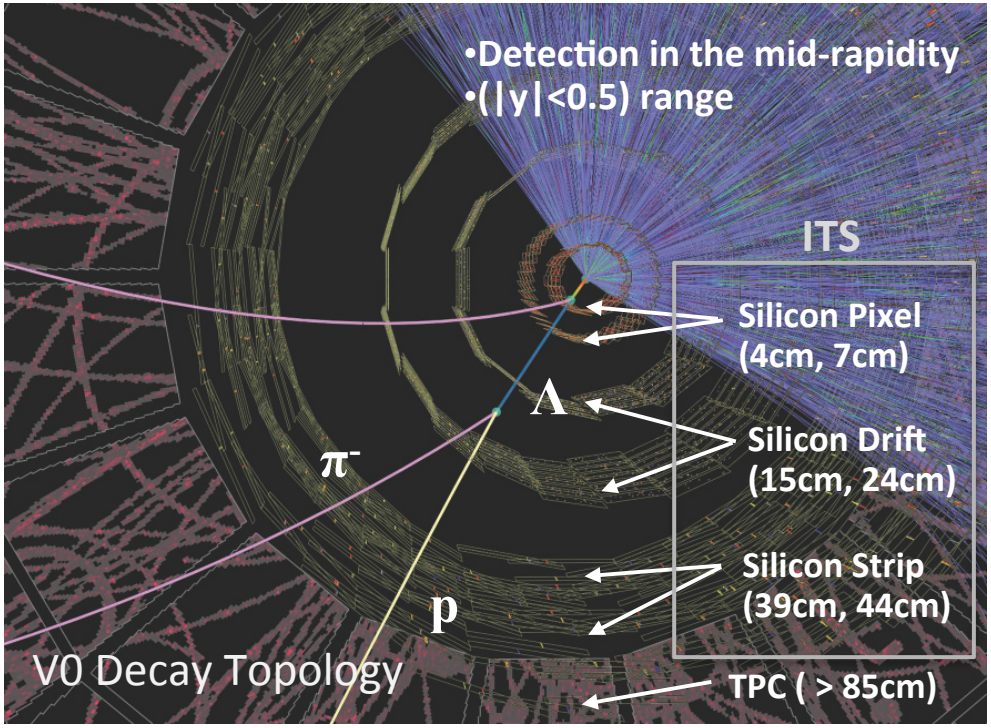
Strange Hadrons in ALICE

Single-Strange

$K^0_S \to \pi^+ + \pi^-$ (B.R. 69.2%)	$\frac{d\bar{s}-s\bar{d}}{\sqrt{2}}$	cτ = 2.68cm
$\Lambda \to p + \pi^-$ (B.R. 63.9%)	uds	cτ = 7.9cm
$\bar{\Lambda} \to \bar{p} + \pi^+$ (B.R. 63.9%)	$\overline{uds}$	cτ = 7.9cm



•Pb-Pb 5.5TeV Hijing MC Event, not all tracks shown; Figure from Alice Physics Performance Report, Volume II (Figure IV)

Strange Hadrons in ALICE

Multi-Strange

$\Xi^- \to \Lambda + \pi^- \to p + \pi^- + \pi^-$	(B.R. 63.9%)	dss	cτ = 4.9cm
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$\Omega^- \to \Lambda + K^- \to p + \pi^- + K^-$	(B.R. 43.3%)	sss	cτ = 2.5cm
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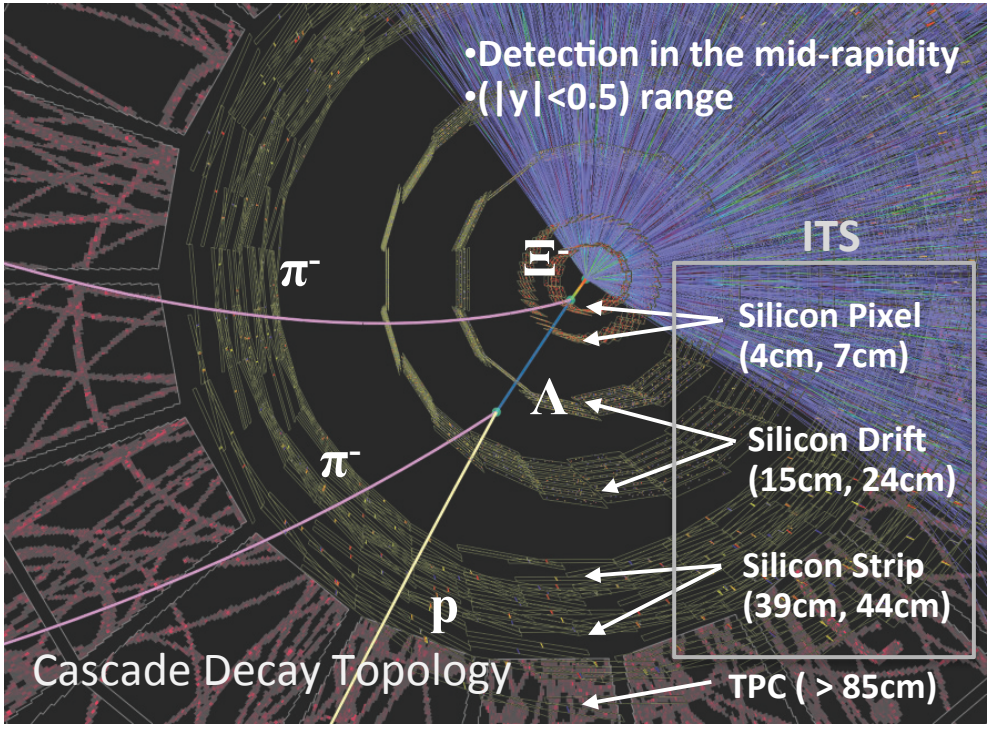

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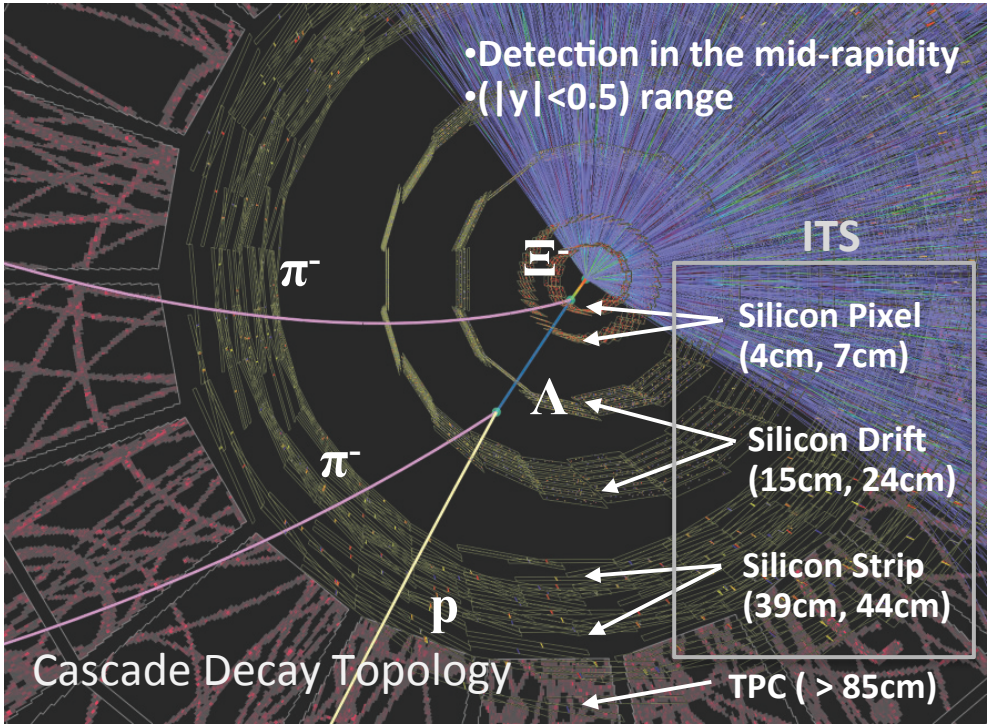


Weak Decays:
Possible identification over a large range of transverse momentum

Track based selections:

→ Topological selection
→ TPC dE/dx selection
→ Competing decay rejection

•*Pb-Pb 5.5TeV Hijing MC Event, not all tracks shown; Figure from Alice Physics Performance Report, Volume II (Figure IV)*

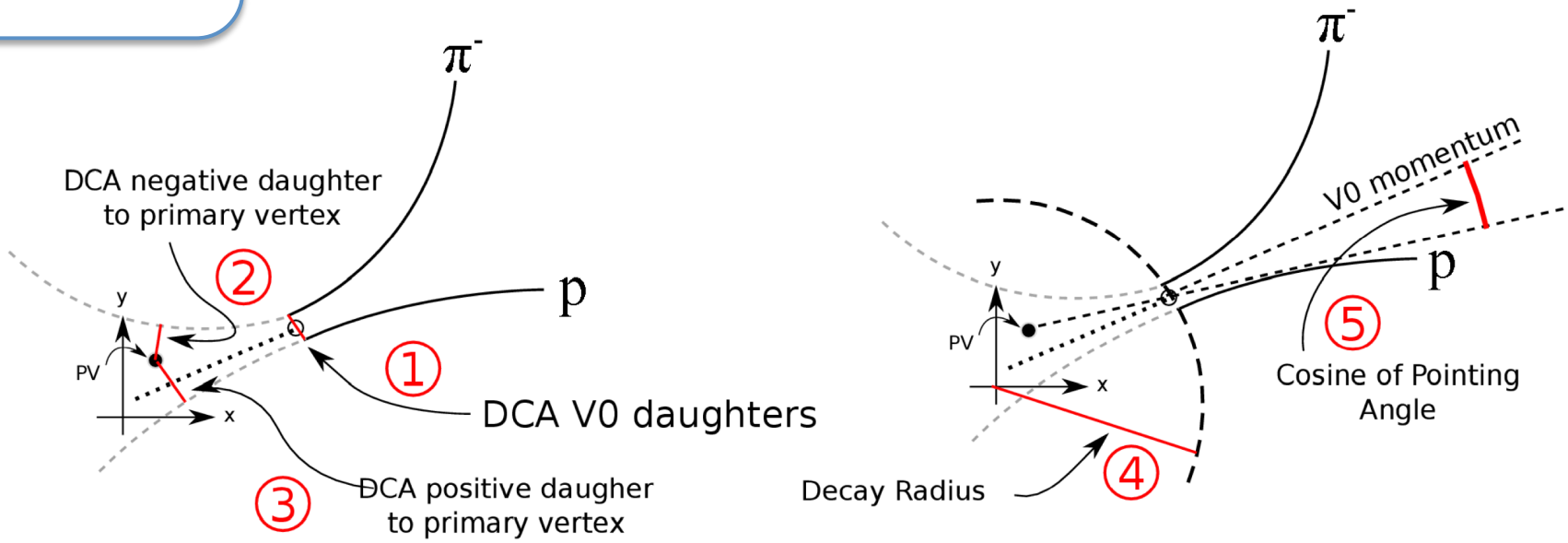
Candidate Selections

Λ, K^0_S

V0 Decays:
5 Variables

Selections:

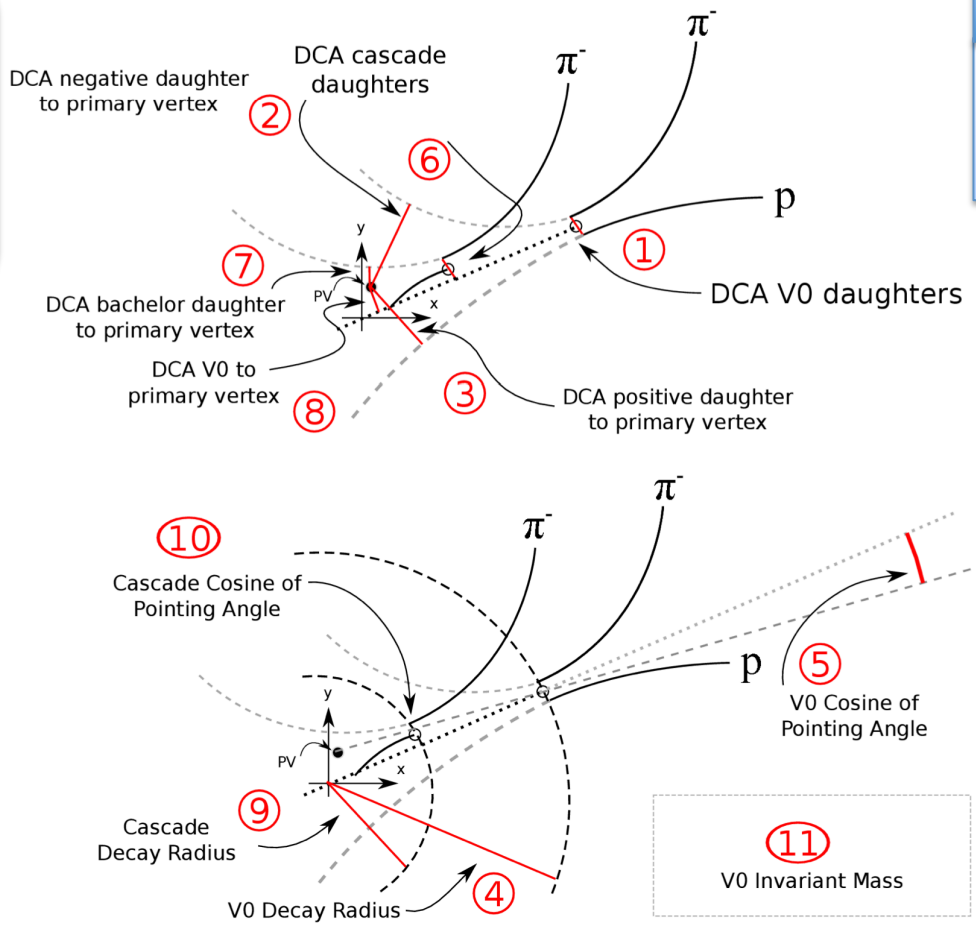
Topological: Use Track Geometry!



Candidate Selections

Ξ^-, Ω^-

Cascade Decays: 11 Variables



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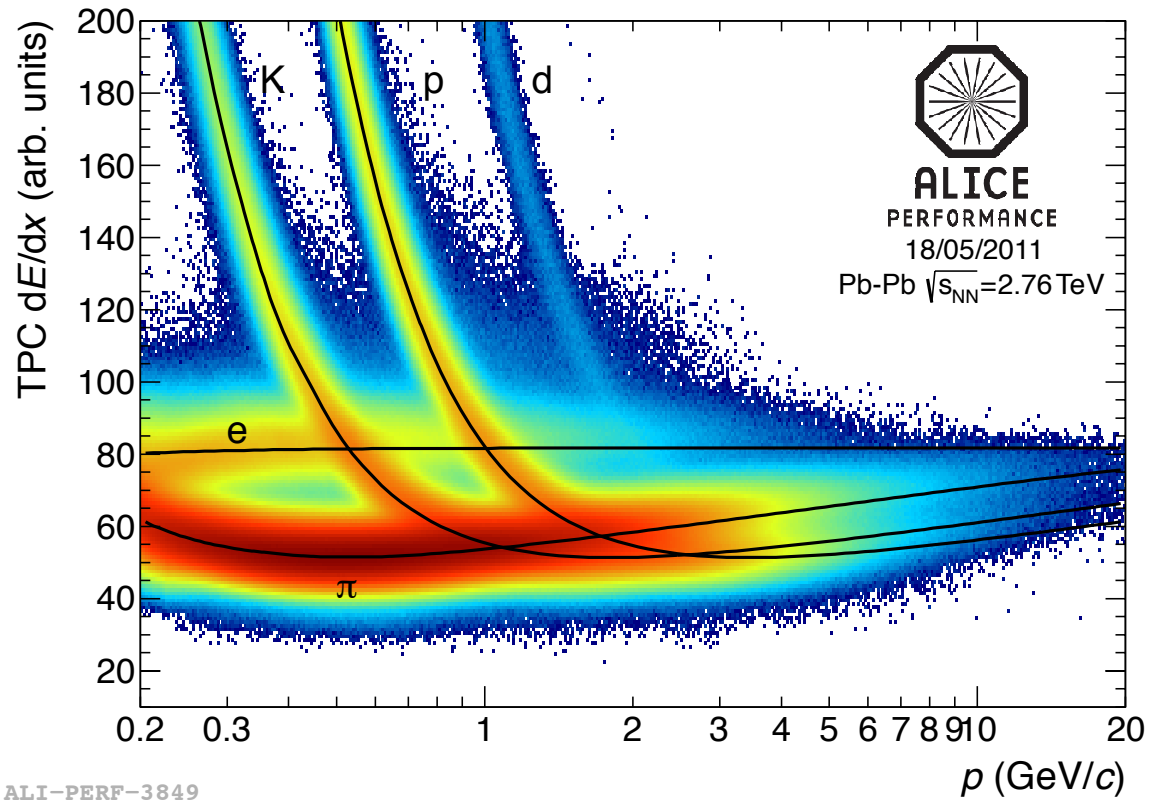

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Energy deposition in the TPC gas (dE/dx)

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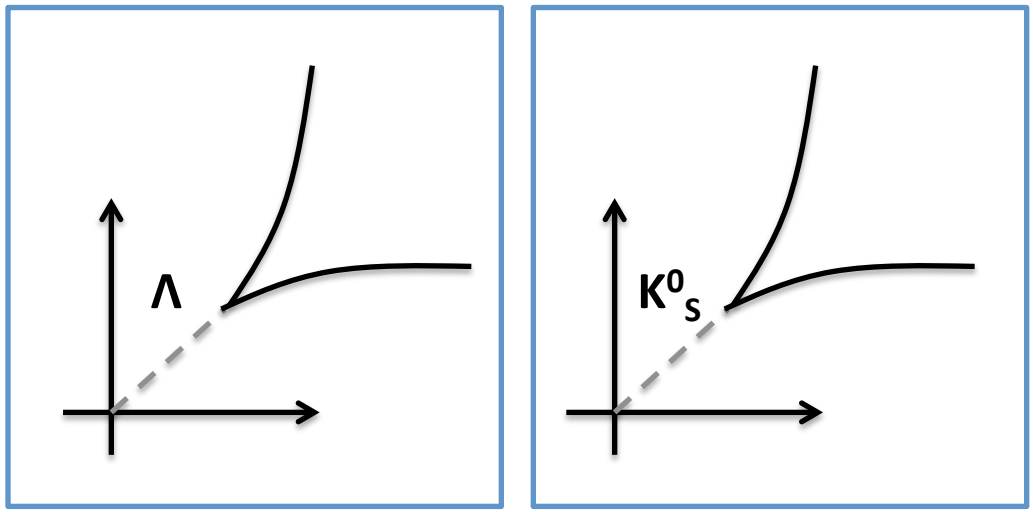


Selections:

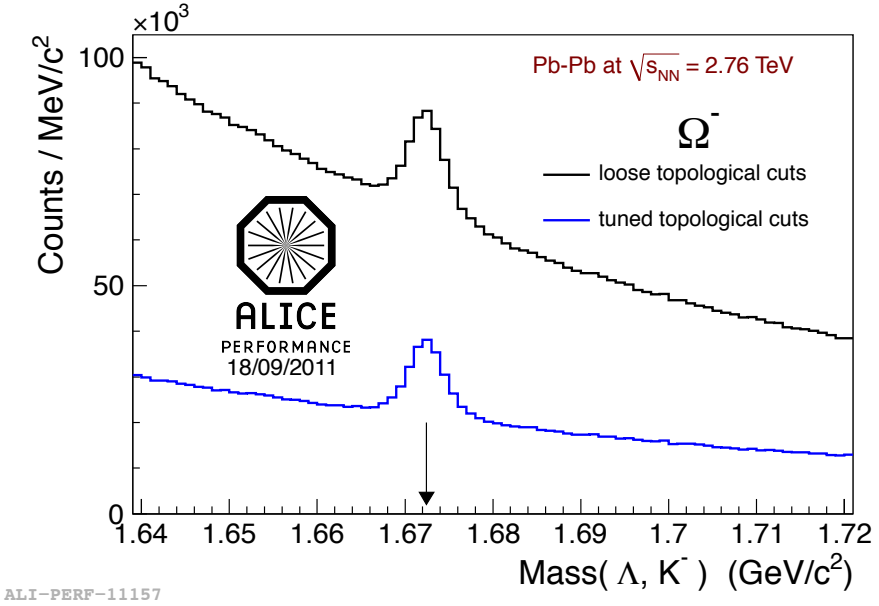
Topological: Use Track Geometry!

Energy deposition in the TPC gas (dE/dx)

If Geometry is the same…
In pp: *Invariant mass rejection of competing V0 species*
In Pb-Pb: *selection for K^0_s to reject Λ decays, similar in spirit but using decay kinematics and asymmetry (details in the backup)*

Invariant Mass Peaks: Signal Extraction

Example: Multi-strange



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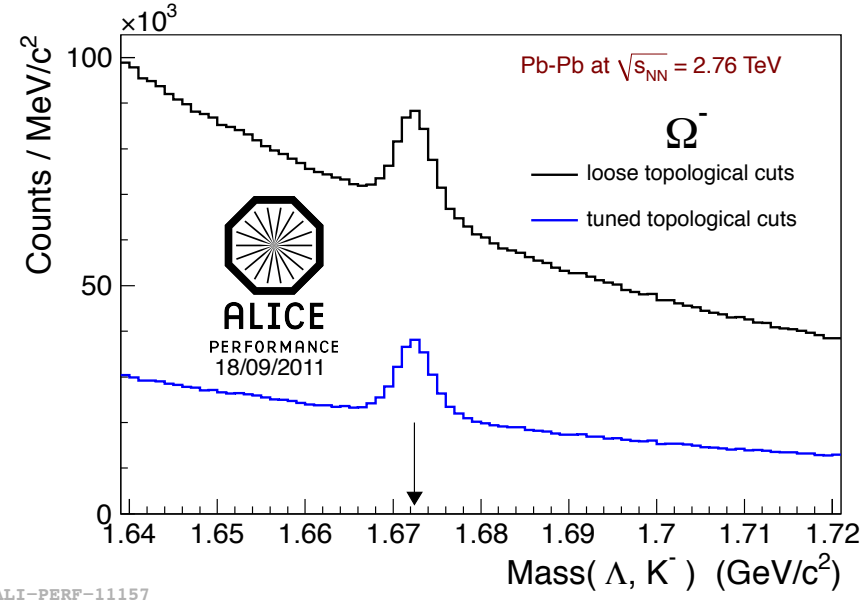

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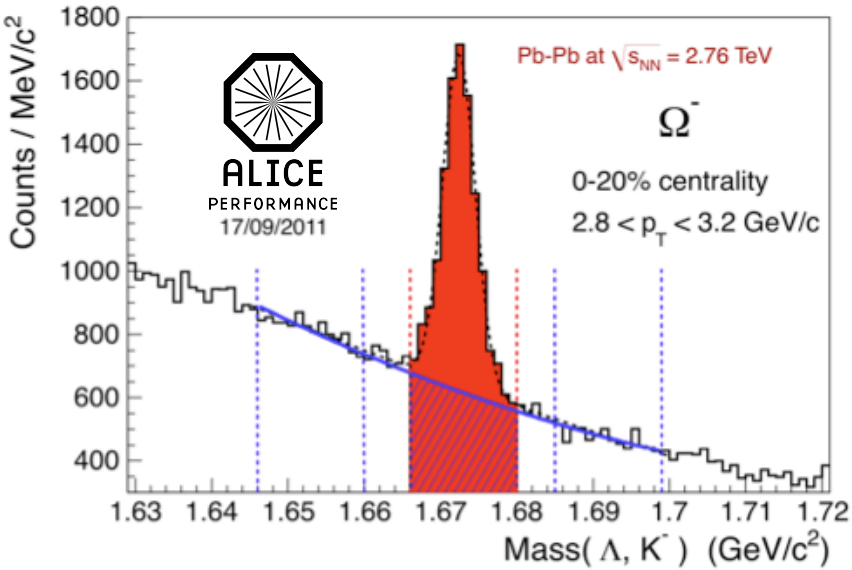
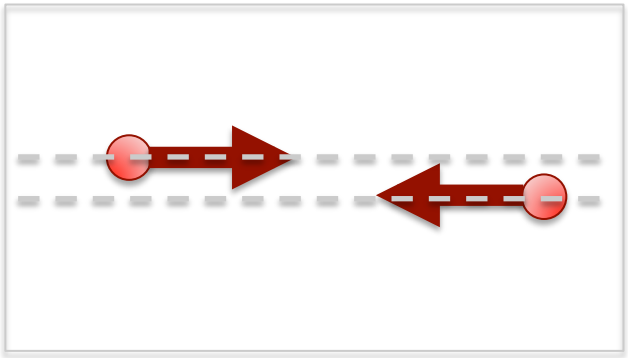


Signal Extraction:

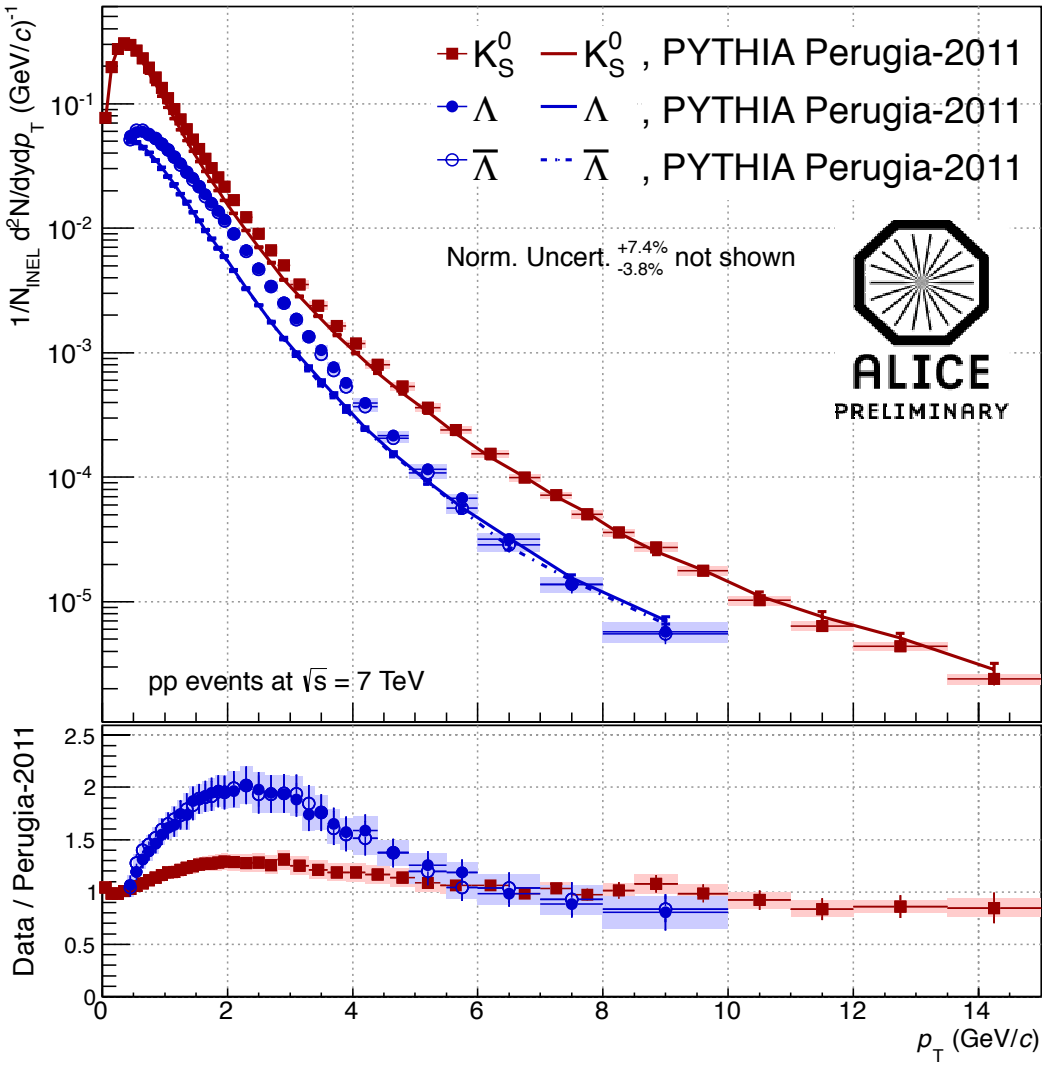
- *Fit Gaussian peak and background for acquisition of peak region*
- *Sample Background close to peak:*
  - *Fit background with a smooth function*
  - *Perform bin counting*
- *Subtract background from peak region*

2. Results from Proton-Proton (pp) Collisions



Proton-Proton at 7 TeV
Results: Single-Strange

p_T Ranges:
K^0_S: 0.0-15.0 GeV/c
Λ: 0.4-10.0 GeV/c



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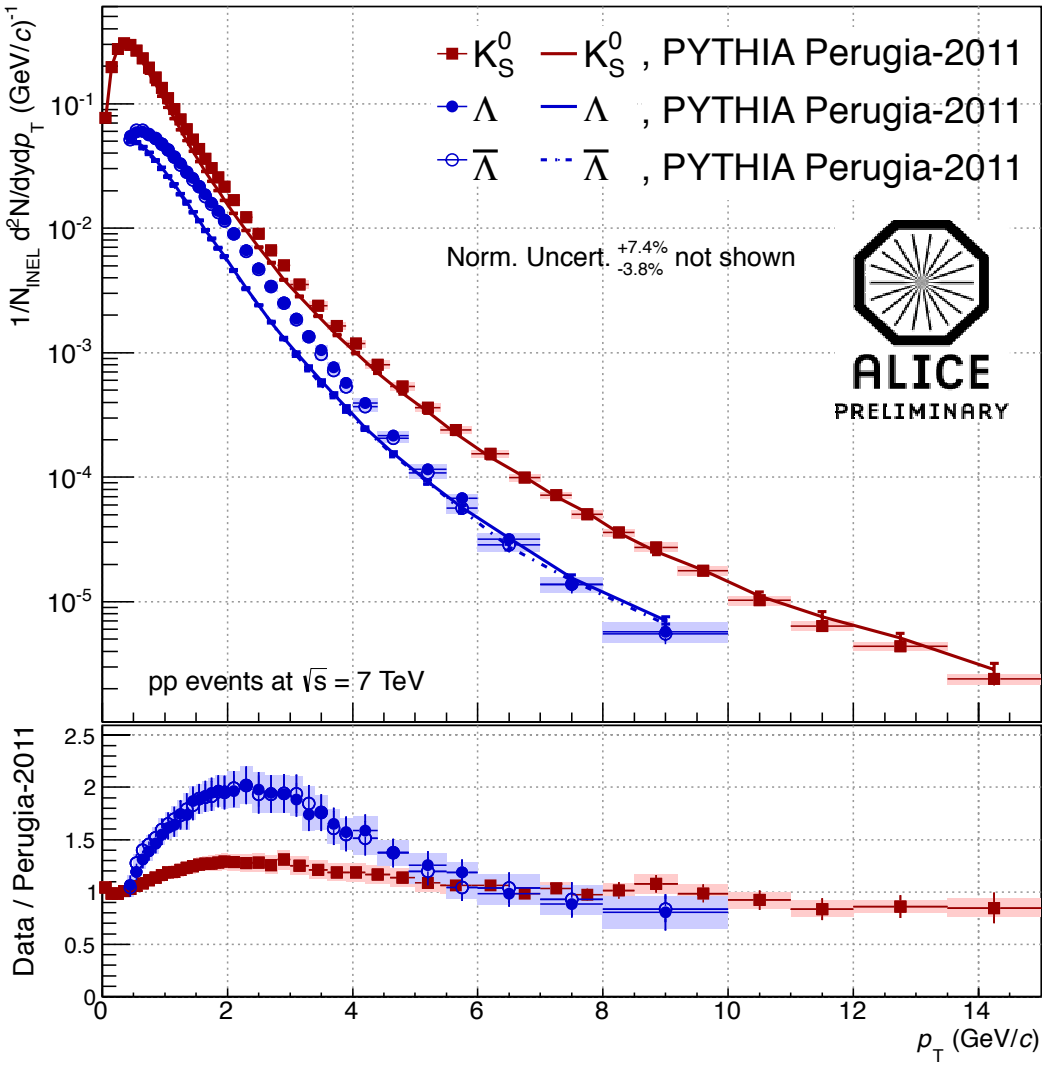

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Antiparticle to particle ratio: compatible with unity

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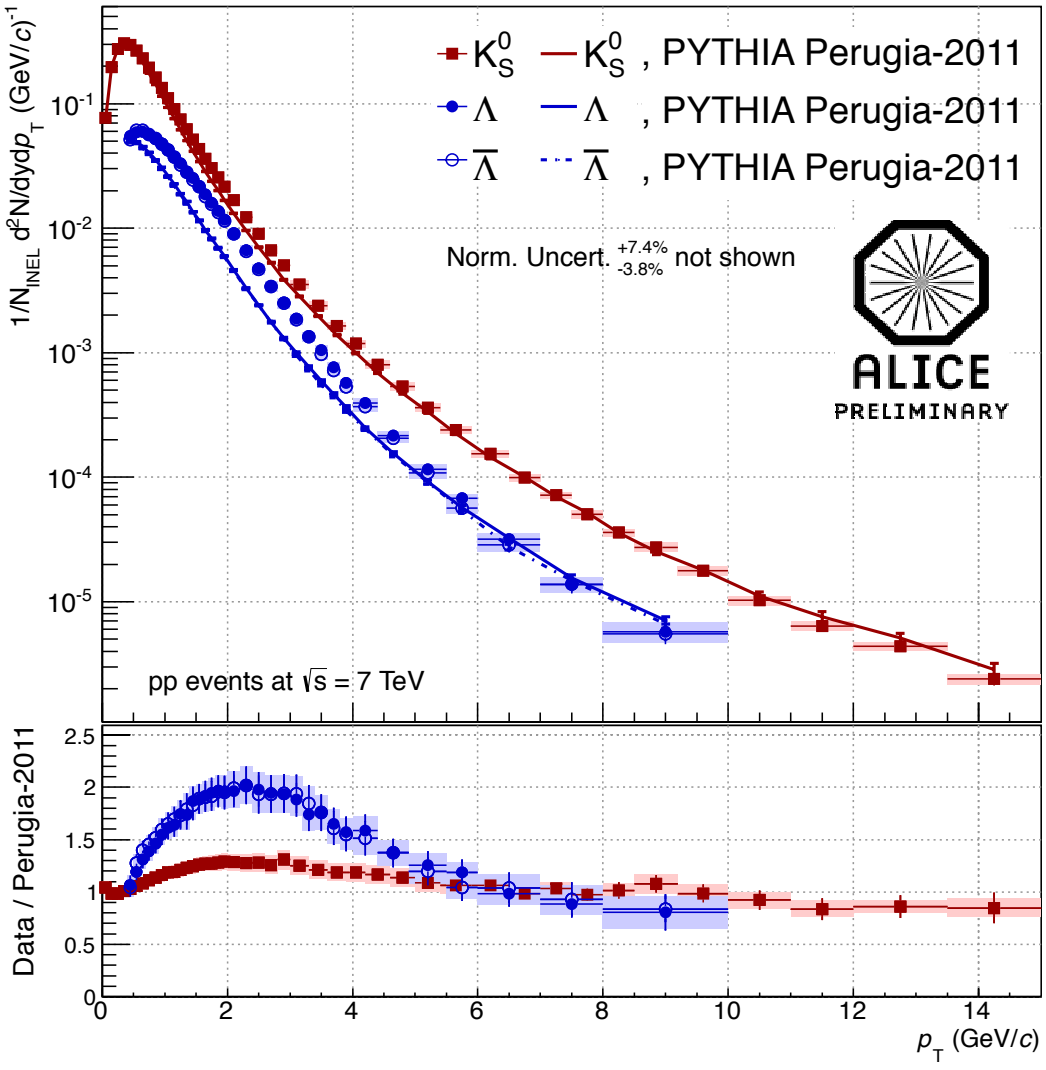

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Comparison to PYTHIA Perugia-2011:

- **Problems in the soft region (more for Λ)**
- **Better agreement for p_T > 7 GeV/c**

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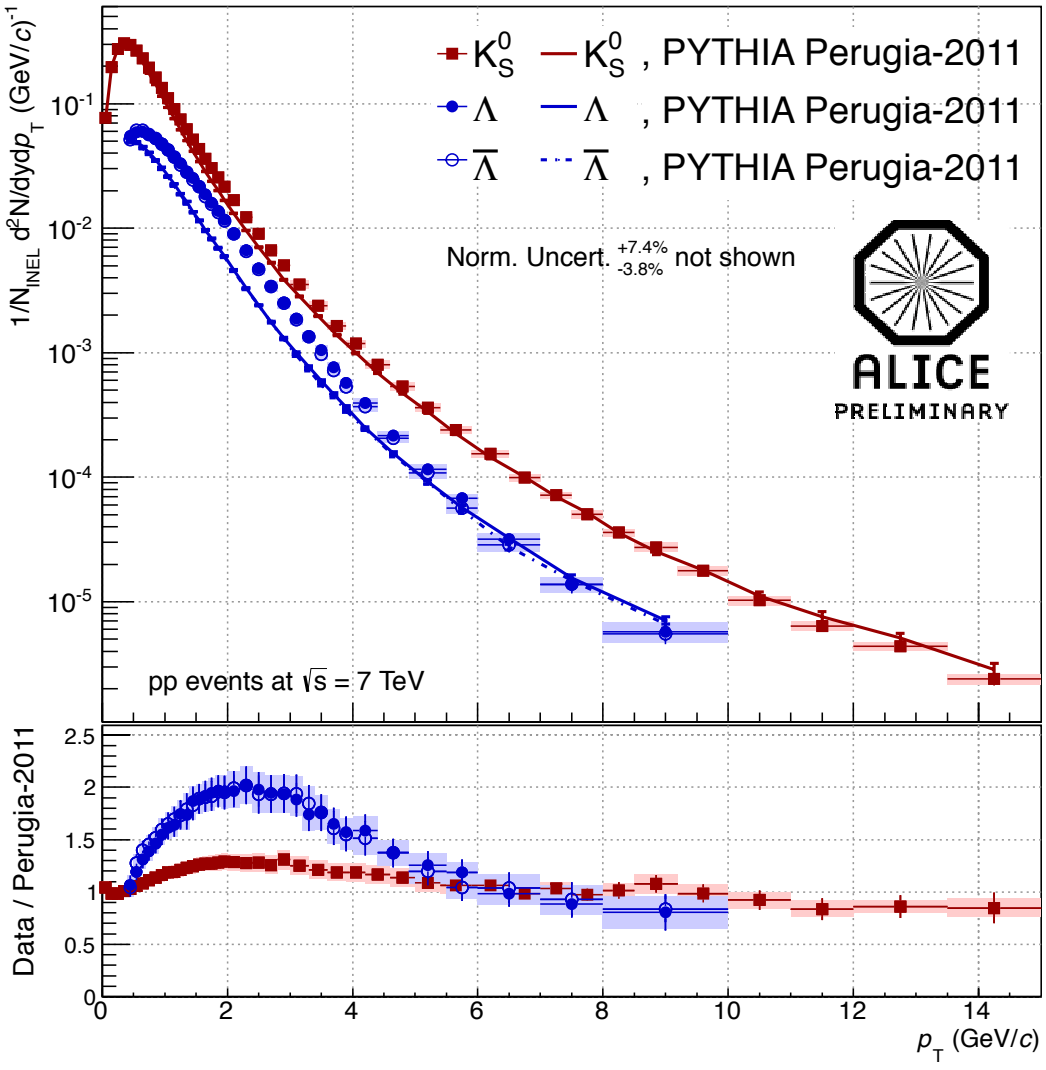

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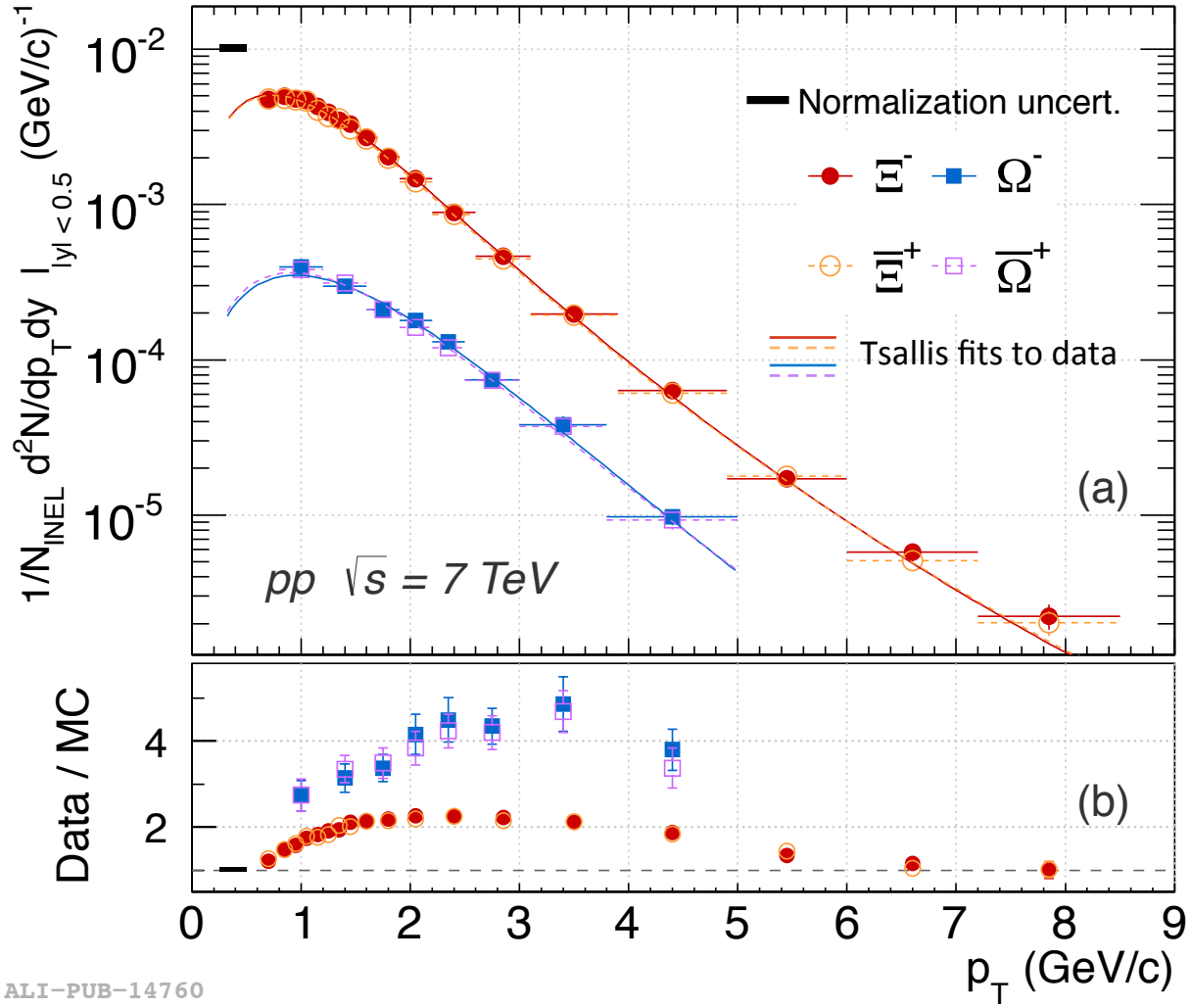
Better MC description at high p_T consistent with other observations: ϕ, K^{*0}: http://arxiv.org/abs/1208.5717

Proton-Proton at 7 TeV
Results: Multi-Strange



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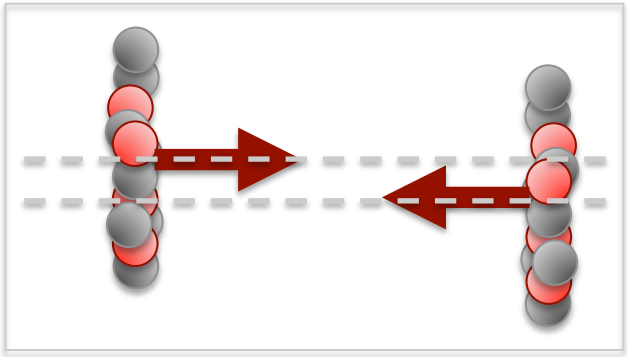
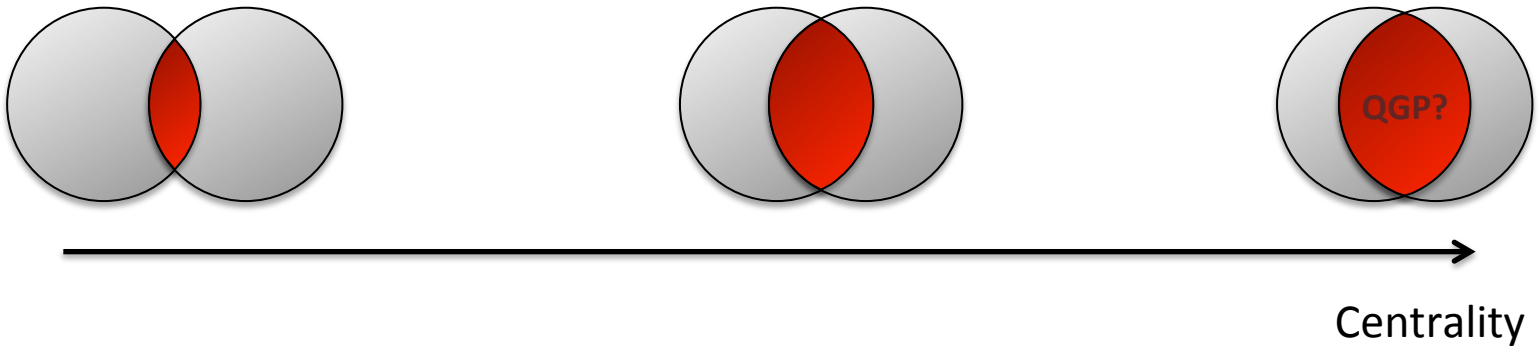
Comparison to PYTHIA Perugia-2011:

- **Deviation in the soft region increases for higher strangeness content**
- **p_T > 7 GeV/c : hint of agreement**

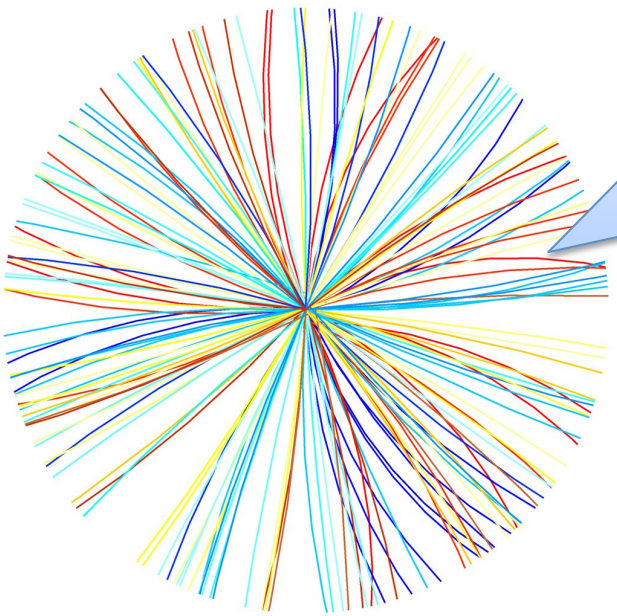
3. Results from Lead-Lead (Pb-Pb) Collisions



Collision Centrality

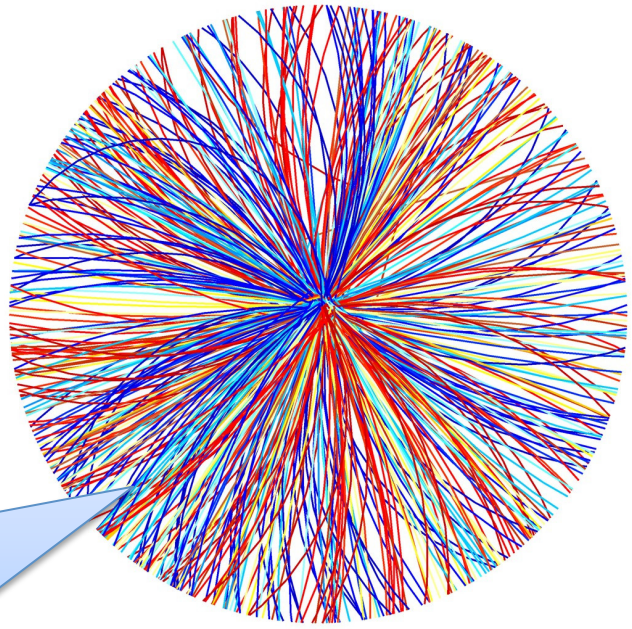


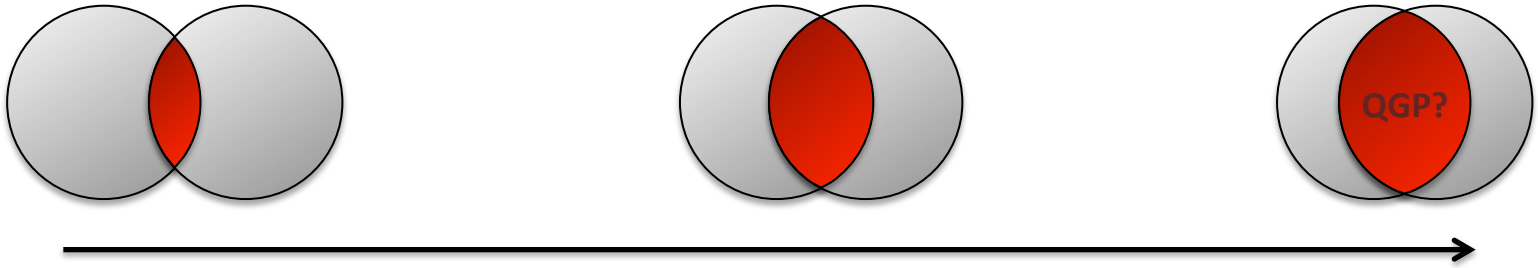
Collision Centrality



Peripheral Collisions
Less Nucleons Participate (N_{part}); *Small(er) particle production rates*

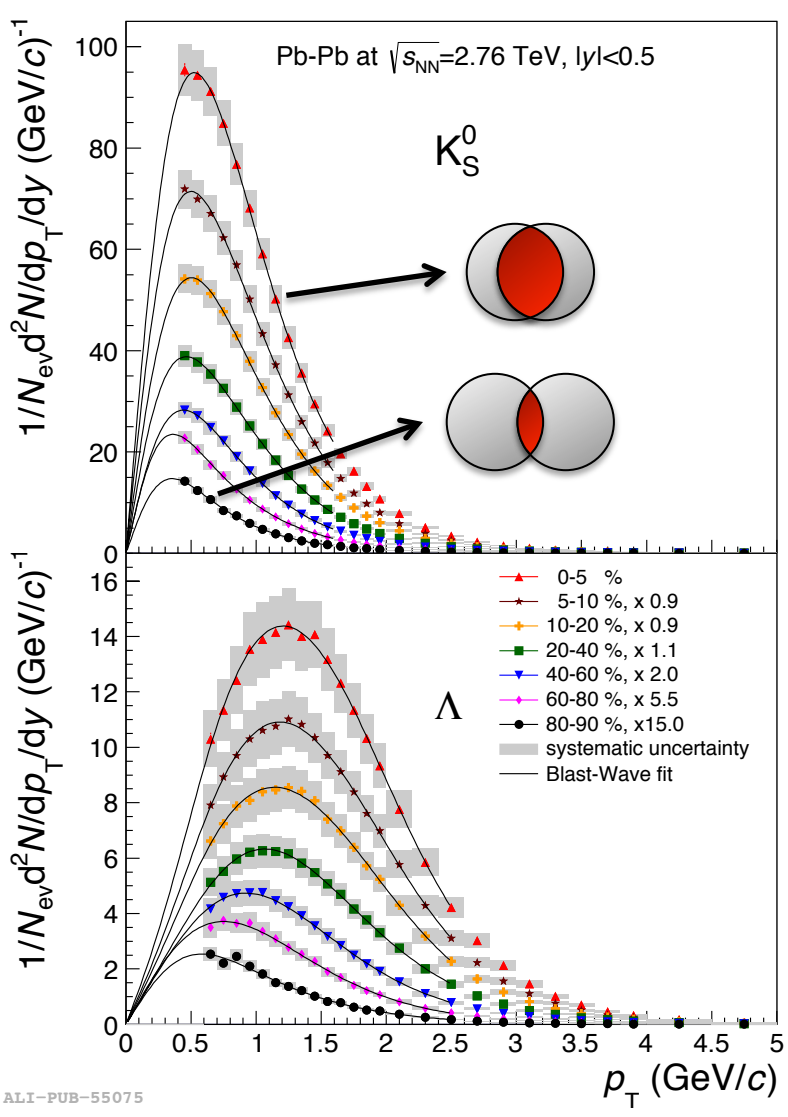
Central Collisions
More Nucleons Participate (N_{part}); *High(er) particle production rates*

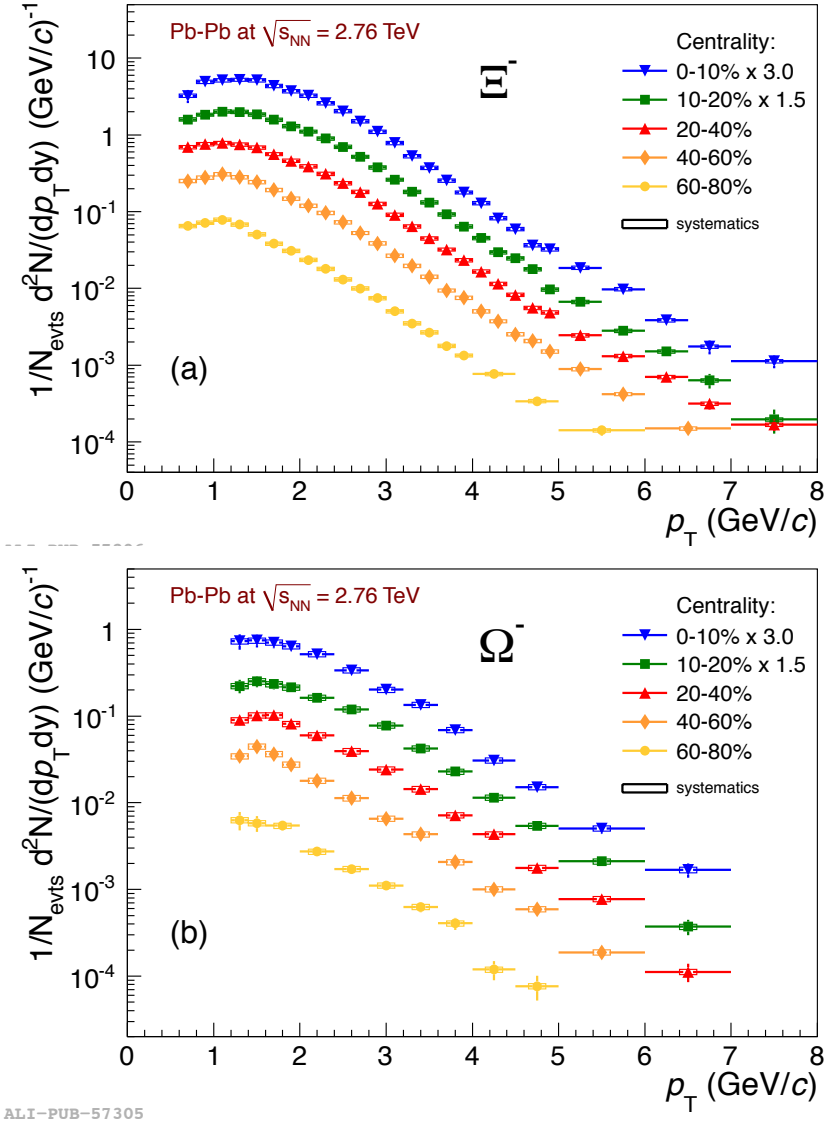




Pb-Pb at 2.76 TeV

Transverse momentum spectra





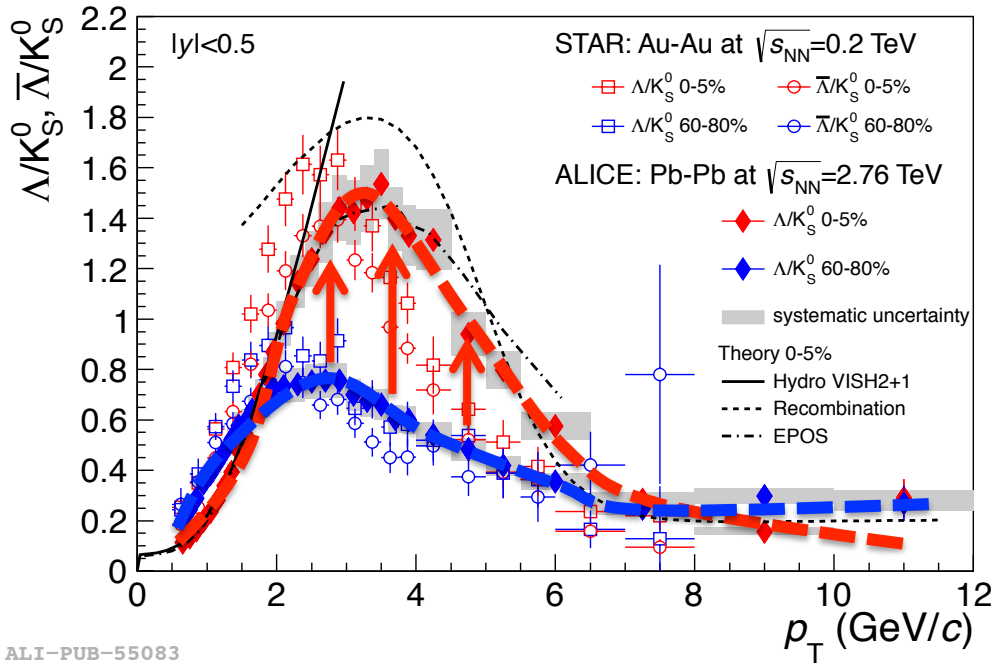
http://arxiv.org/abs/1307.5543

Phys. Rev. Lett. 111, 222301 (2013)

QGP Signature 1:

Baryon to Meson Ratio

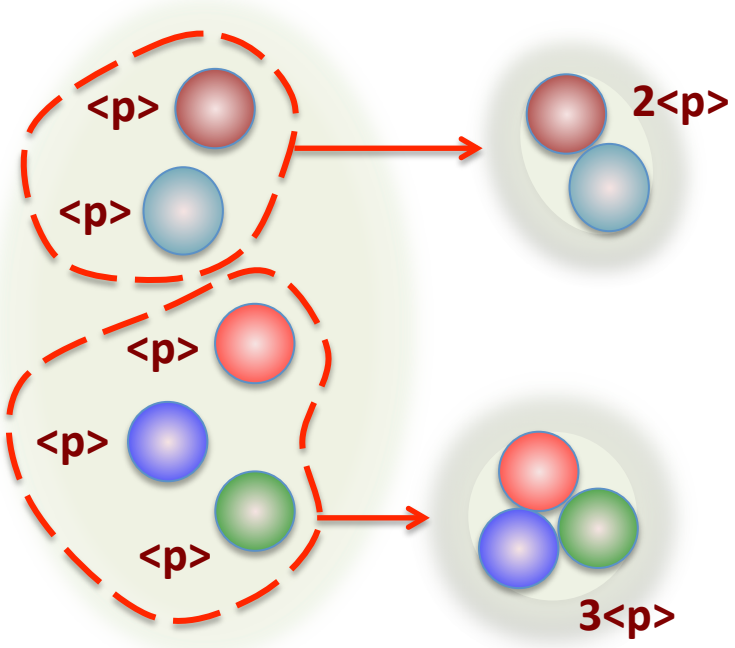
Phys. Rev. Lett. 111 (2013) 222301



Particle Production by

-> Parton Coalescence

- *Produces both baryons and mesons*
- *baryons will have larger mean momenta <p>*



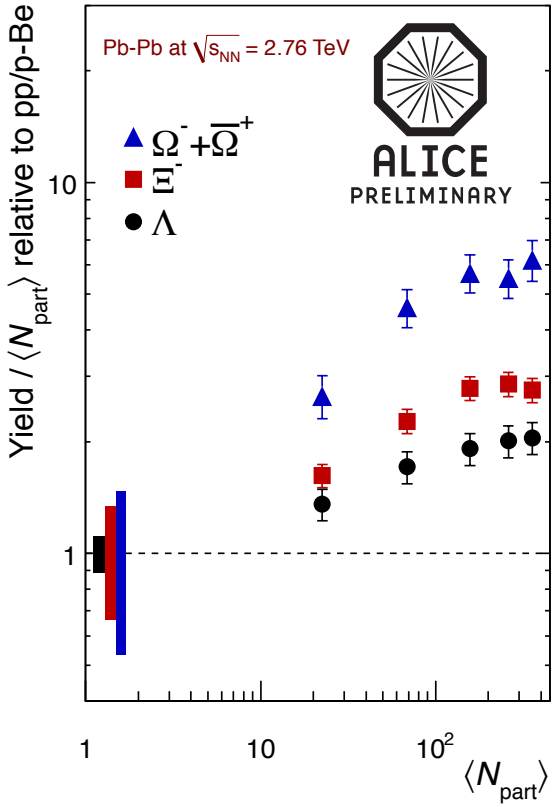
Increased relative production of baryons at intermediate transv. Momentum (2-4 GeV/c):

"Baryon Anomaly"

QGP Signature 2:

Strangeness Enhancement

arXiv:1307.5543



ALI-DER-57382

$$E_i = \frac{\frac{Yield_i^{AA}}{\langle N_{part} \rangle}}{\frac{Yield_i^{pp}}{2}}$$

Enhancement larger for hadrons with higher strangeness content

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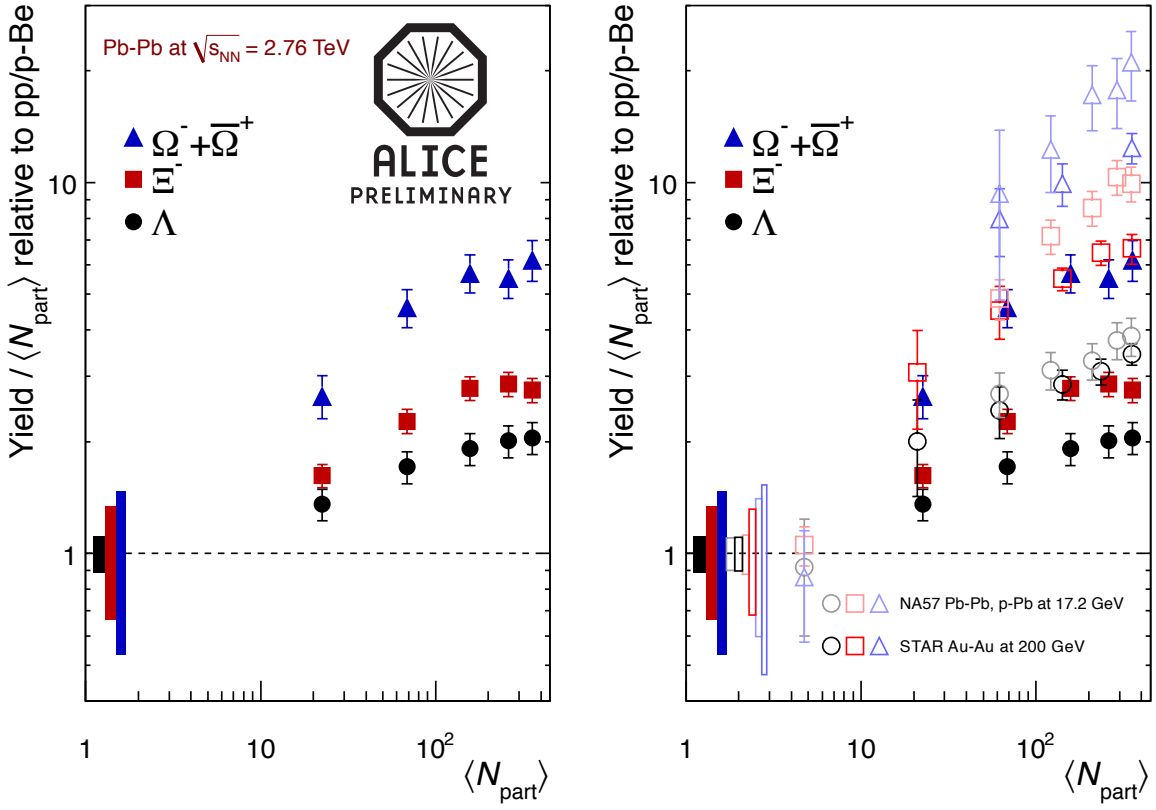

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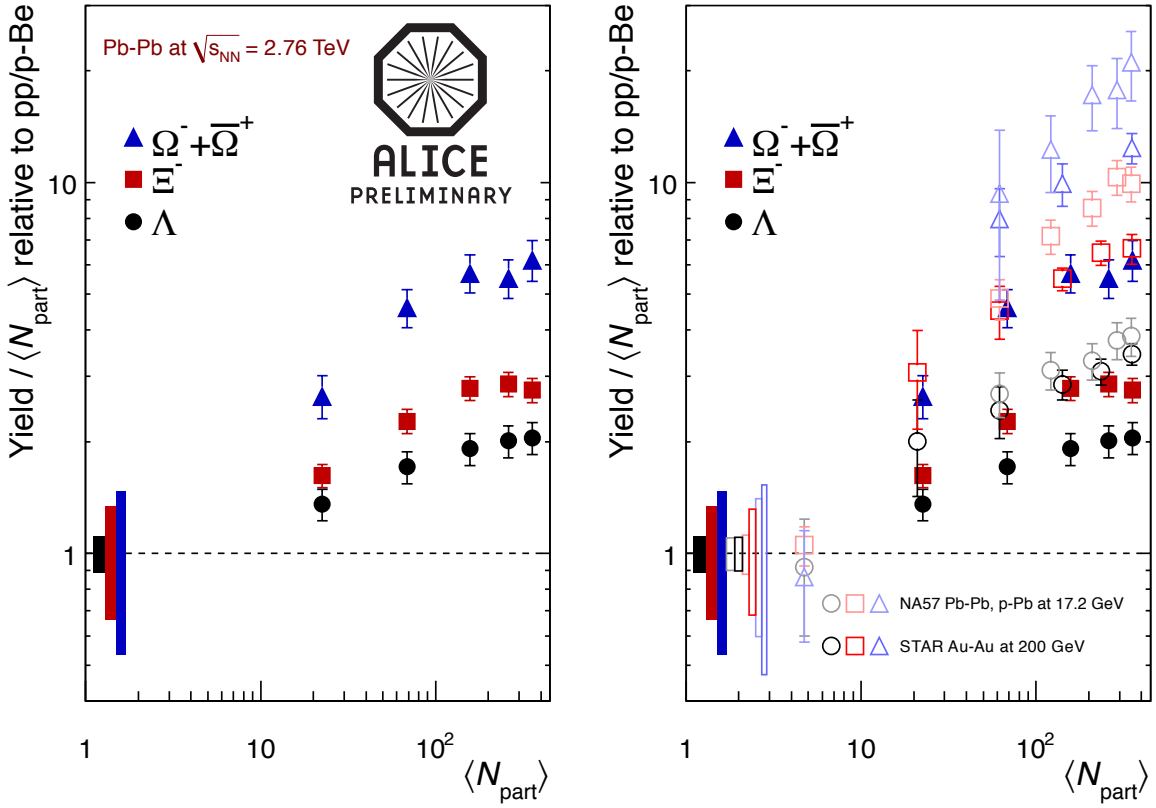

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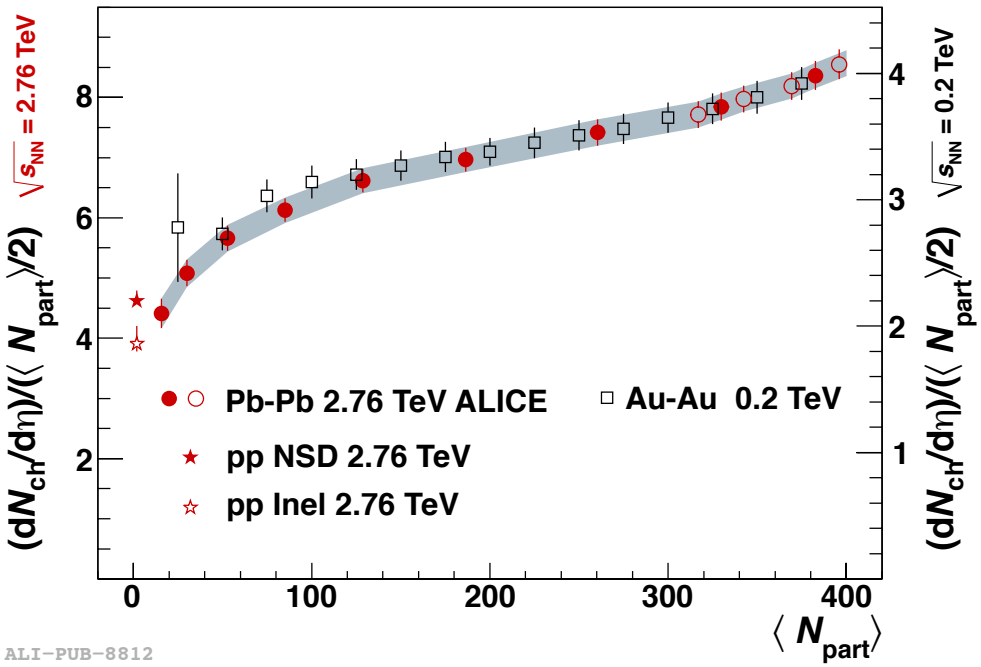
But is that the whole story? Is N_{part} a good scale?

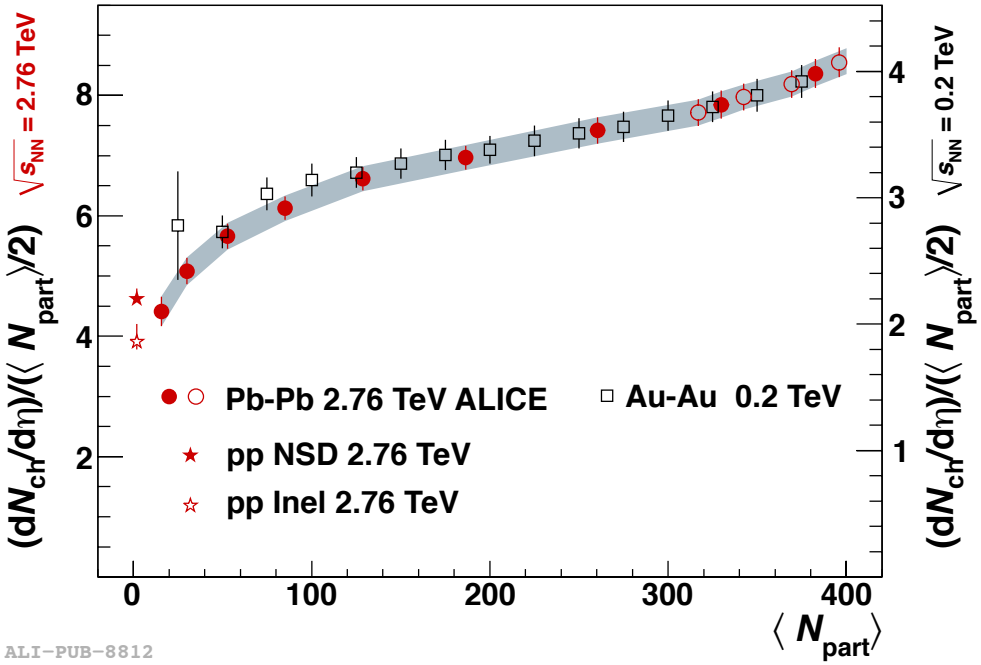
Strangeness Enhancement vs Non-Strange?



Not Really: The number of produced Charged particles isn't proportional to the number of participant nucleons…

Strangeness Enhancement vs Non-Strange?

Phys. Rev. Lett. 106 (2011) 032301



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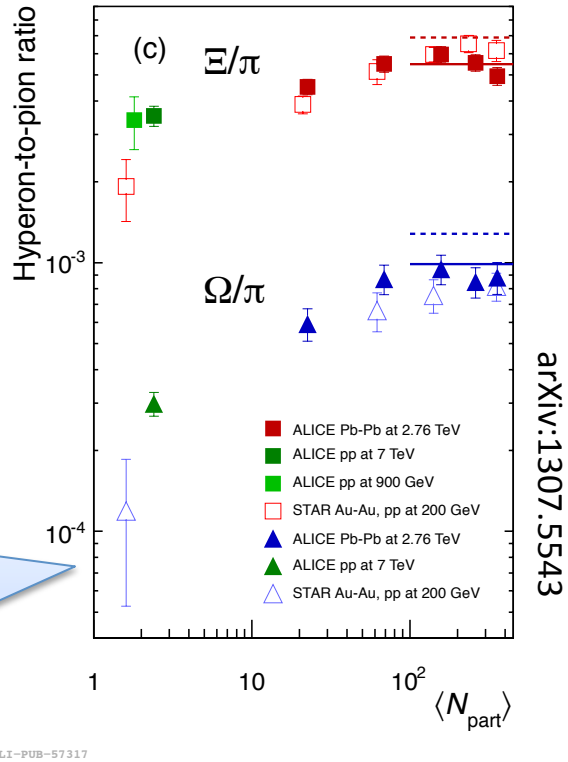
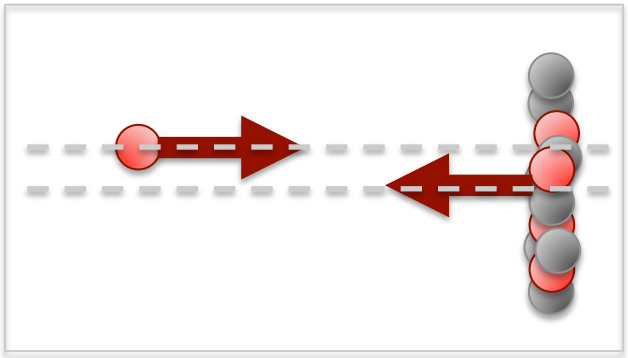


Multi-Strange Baryon to Pion yields: increase for more central events. A strangeness enhancement of about 2-3 is there!

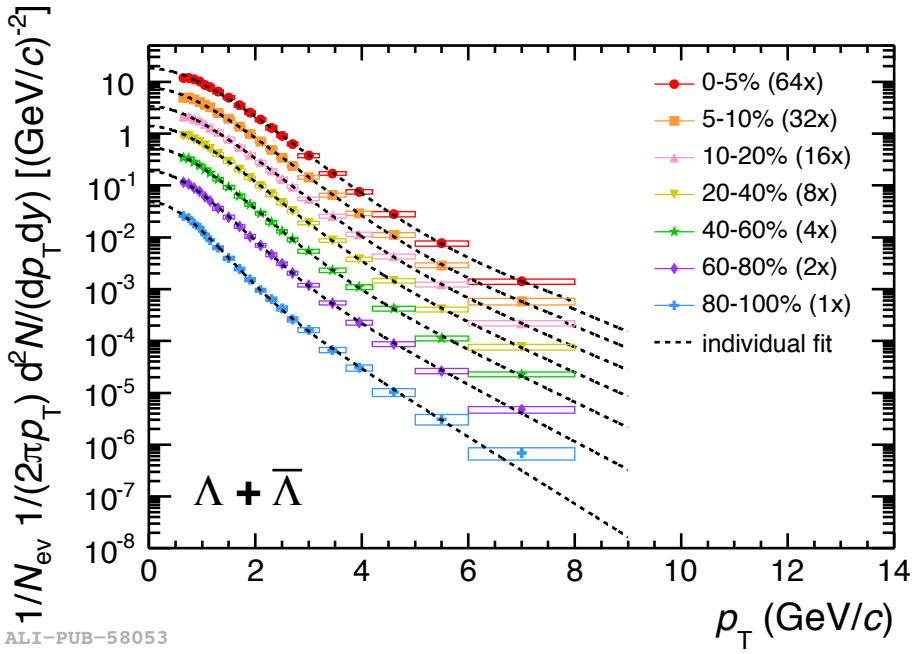
4. Results from Proton-Lead (p-Pb) Collisions

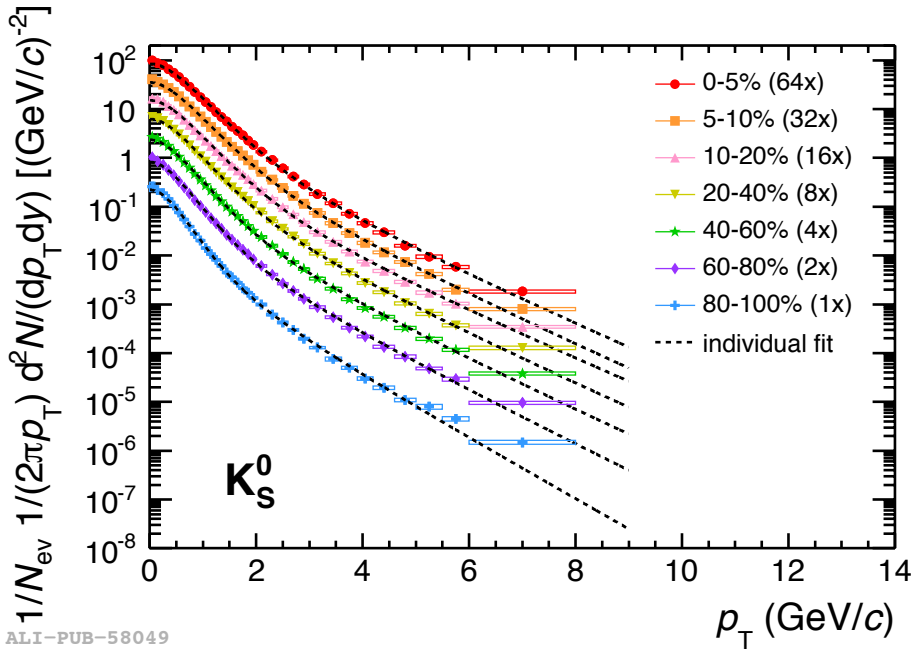


p-Pb at 5.02 TeV

Single-Strange Spectra

arXiv:1307.6796

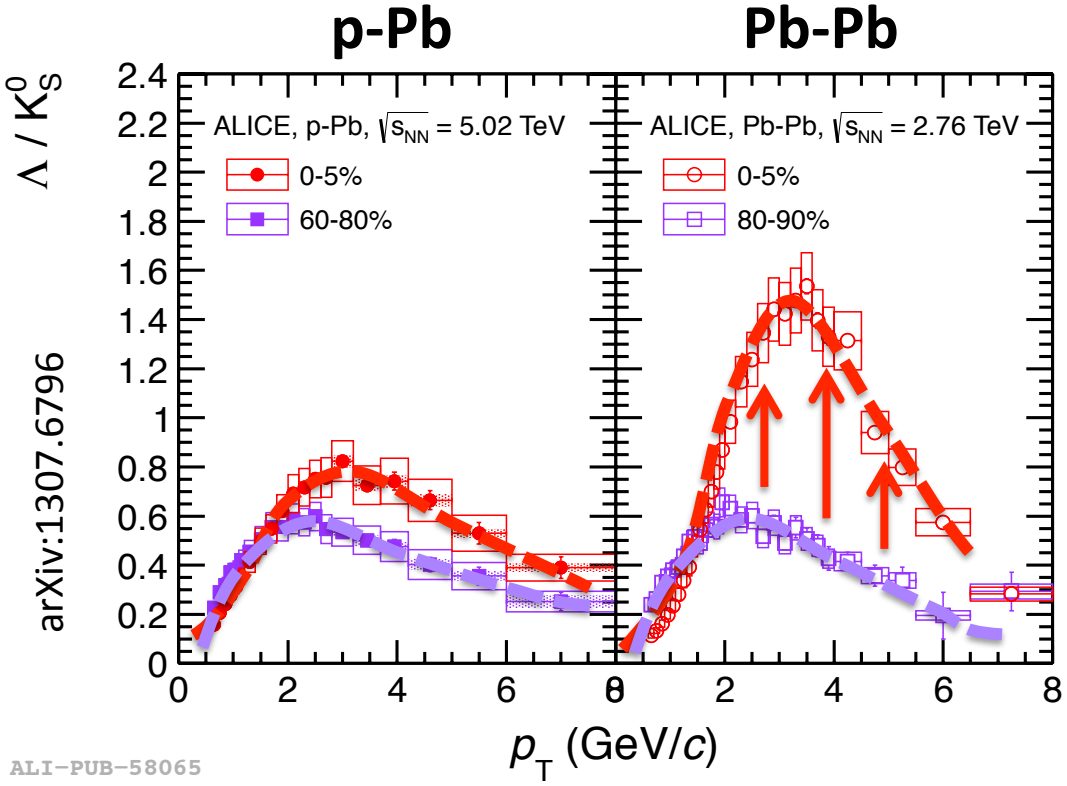




- Spectra binned in *multiplicity* (quantiles of VZERO cross-section)
- Λ, K0s spectra are *harder* for large multiplicities

p-Pb at 5.02 TeV

Baryon Anomaly in p-Pb?



Λ/K⁰s ratio vs multiplicity:

- Increase at mid- to high p_T
- Corresponding depletion at low p_T
- *Qualitatively same behaviour as Pb-Pb!*

p-Pb at 5.02 TeV

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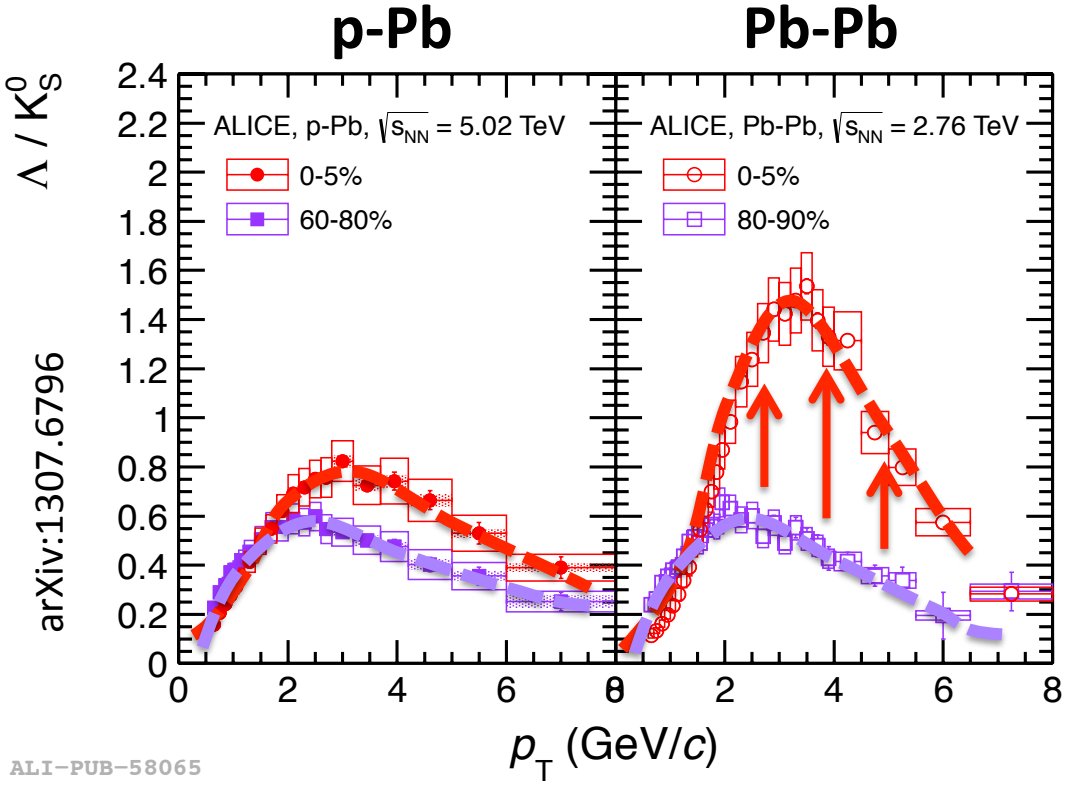

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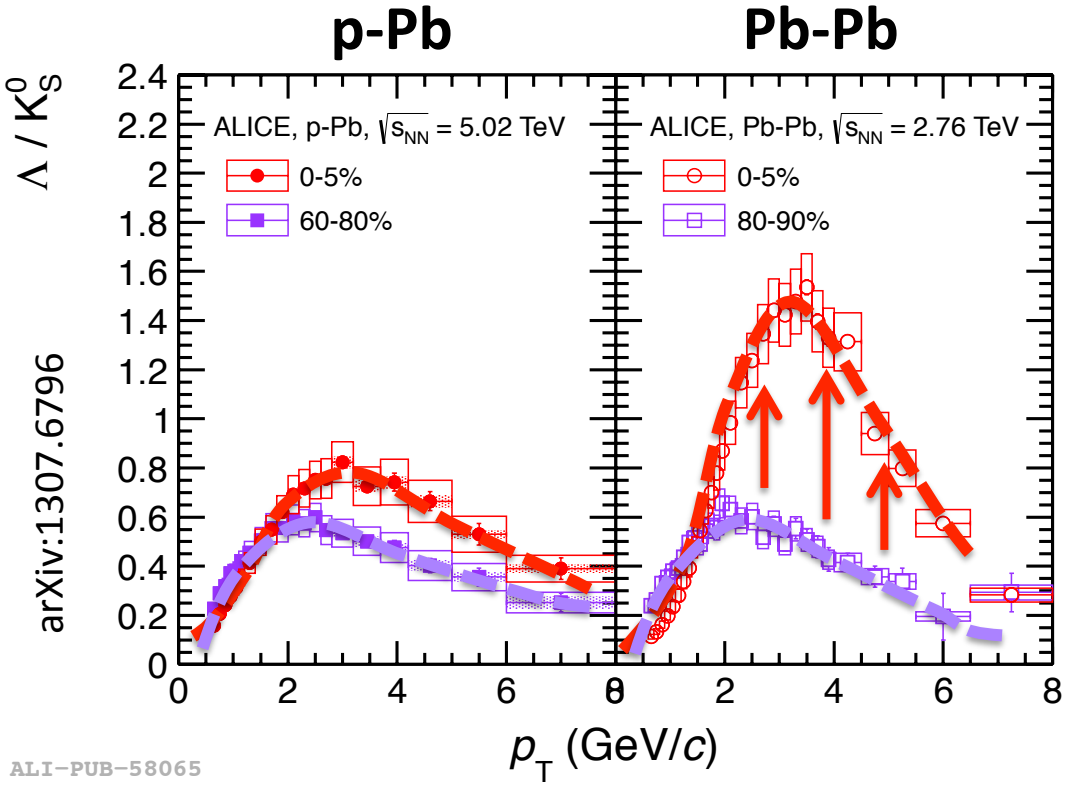

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What about the Ξ and Ω ?

Conclusions

- *Systematic Measurements of strange and multi-strange particles have been performed in pp, p-Pb and Pb-Pb collisions*

- **Proton-proton (pp)**:
  Serves as a reference for Pb-Pb (a "hadron gas")
  PYTHIA, a pQCD-inspired model, predicts K^0_s yields reasonably but fails for baryons, and more so for higher strangeness content.

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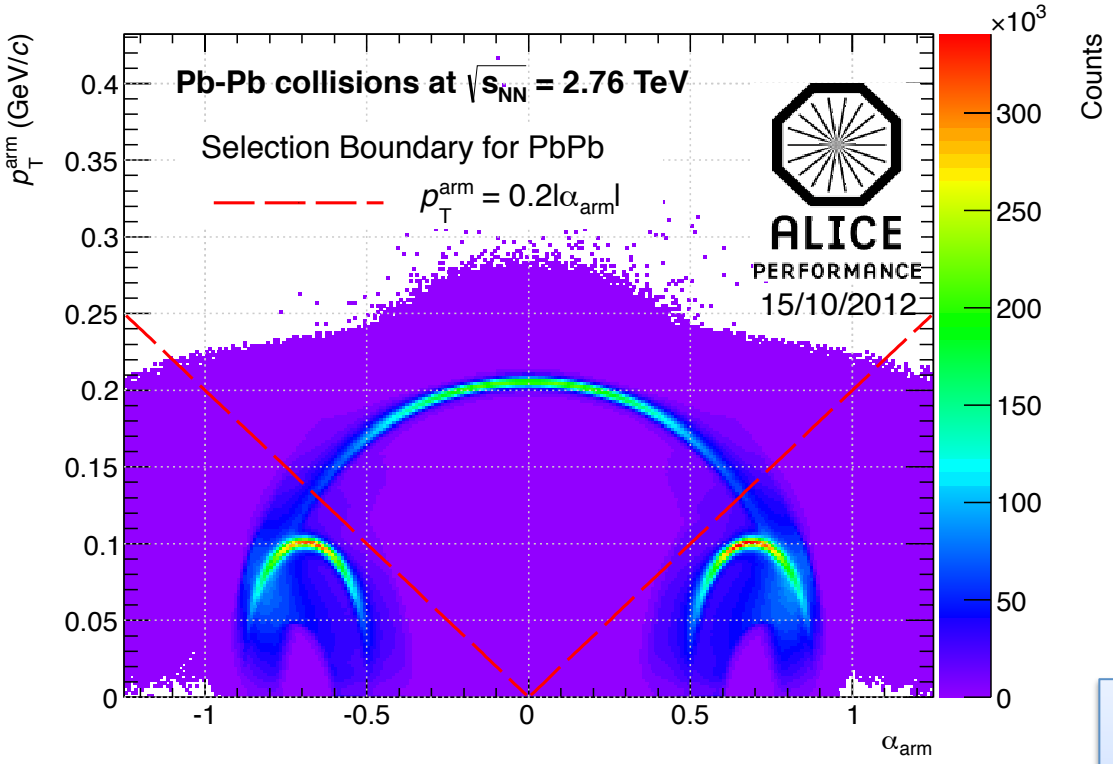
Thank you!

BACKUP

Candidate Selections



α_{arm}: asymmetry in longitudinal momentum distribution
p_T^{arm}: total transverse momentum of daughters
(longitudinal and transverse directions with respect to V0)

Selections:

Topological: Use Track Geometry!

Energy deposition in the TPC gas (dE/dx)

In pp: *Invariant mass rejection of competing V0 species*
In Pb-Pb: *Armenteros-Podolanski selection for* K^0_s

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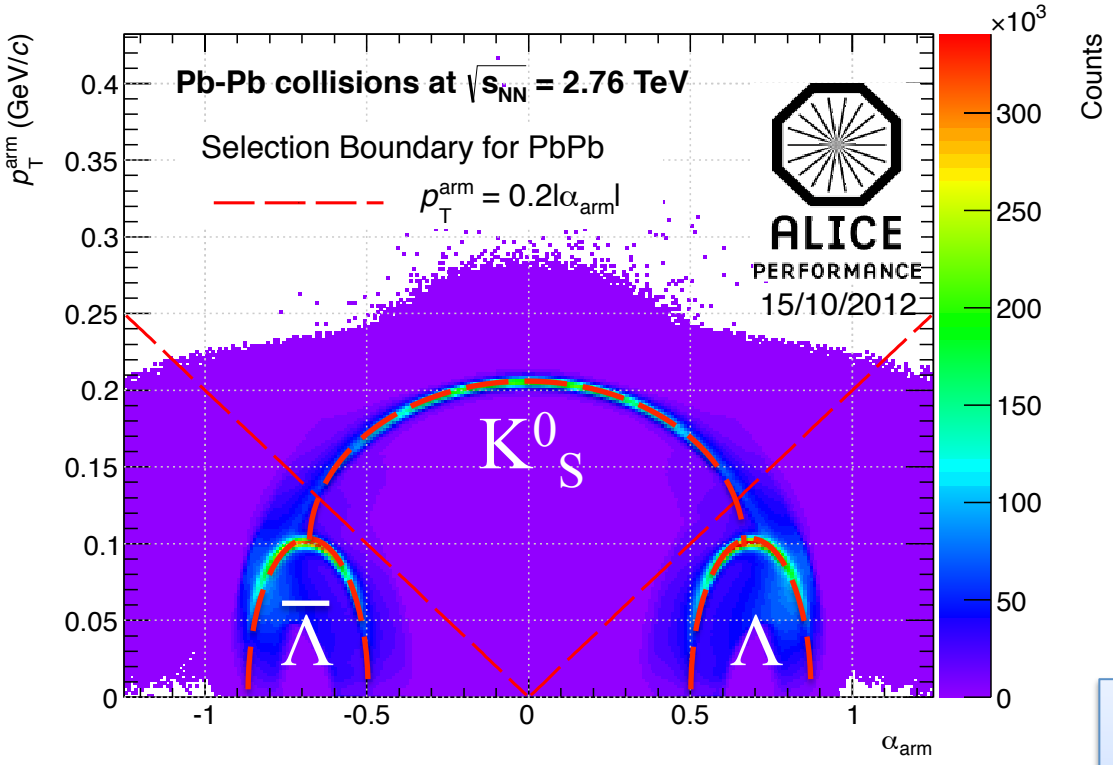

- Selection for K^0_s: $p_T^{arm} > 0.2\ |\alpha_{arm}|$
- Restricts Phase space of daughters
- Checked: does not introduce false peaks

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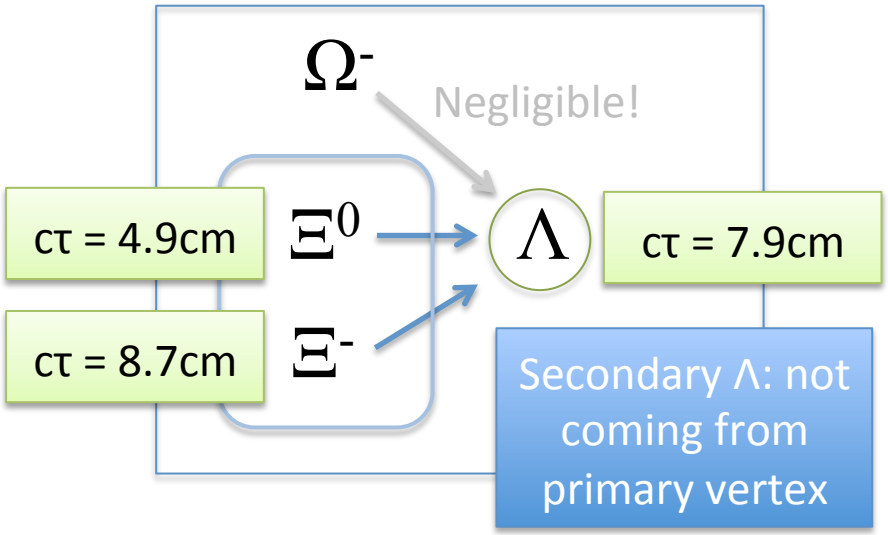
Feeddown Subtraction for Λ



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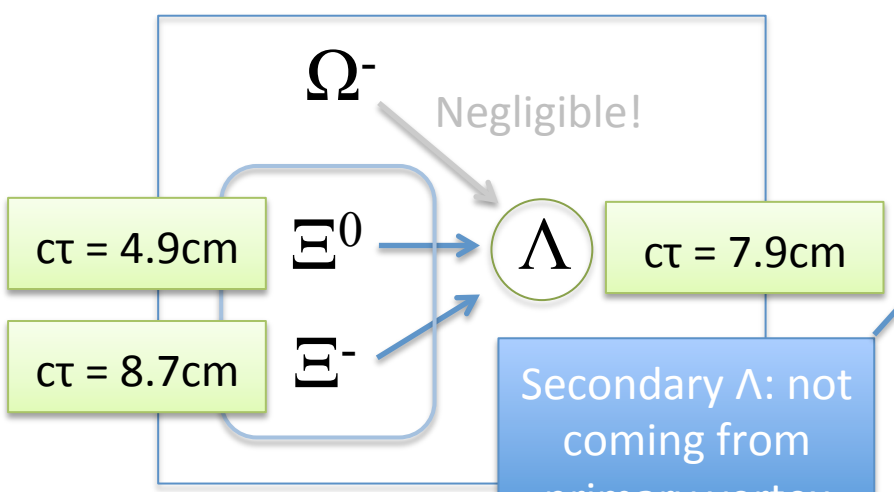


Desired Measurement requires subtracting an estimated Λ raw yield coming from Ξ

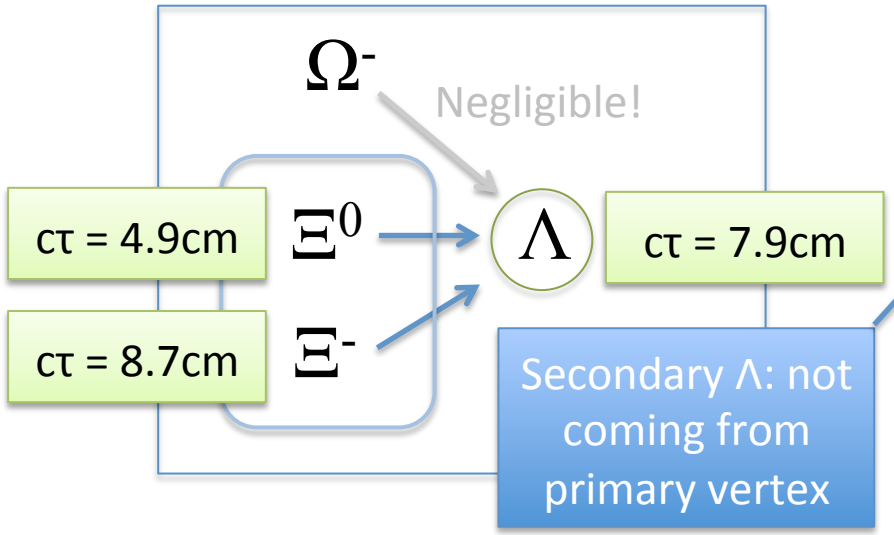
How does the Λ from Ξ enter the analysis?

- *Compute Feeddown Matrix*

In what magnitude does it contribute?

- *Use a Ξ measurement as weight*

Feeddown Subtraction for Λ



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$$F_{ij} = \frac{N_{reco}\,(\Lambda)^{\text{in bin i}}_{\text{from } \Xi \text{ bin j}}}{N_{gen}\,(\Xi)_{\Xi \text{ bin j}}}$$

$$\Lambda^{raw}_{primary} = \Lambda^{raw}_{measured} - \sum_j F_{ij} \int_{p_t(bin)} \frac{dN}{dp_t}\,(\Xi^-)$$

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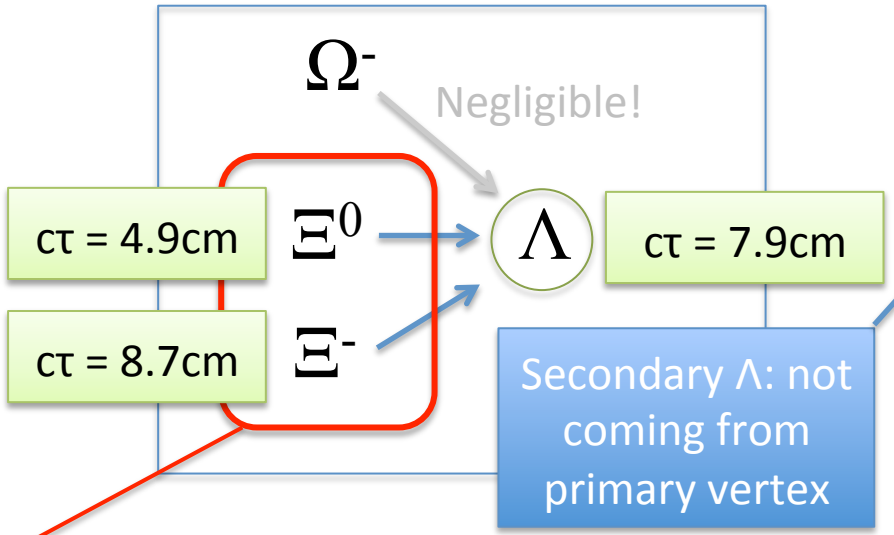

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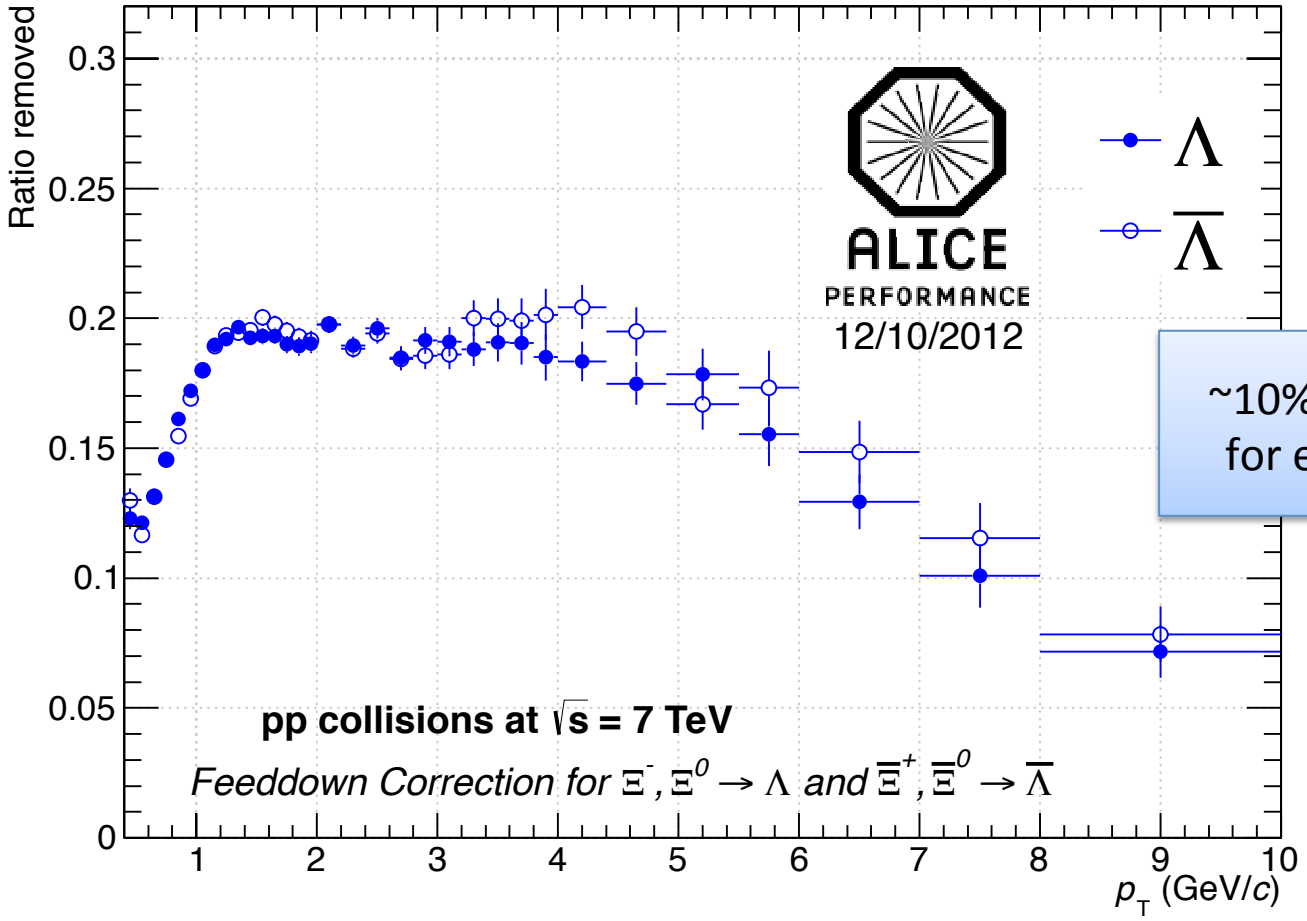
Two methods for considering Ξ^0 tested:

- Fill F_{ij} with Λ coming from both charged and neutral Ξ
- Multiply charged Ξ feeddown by 2

Consistent Results

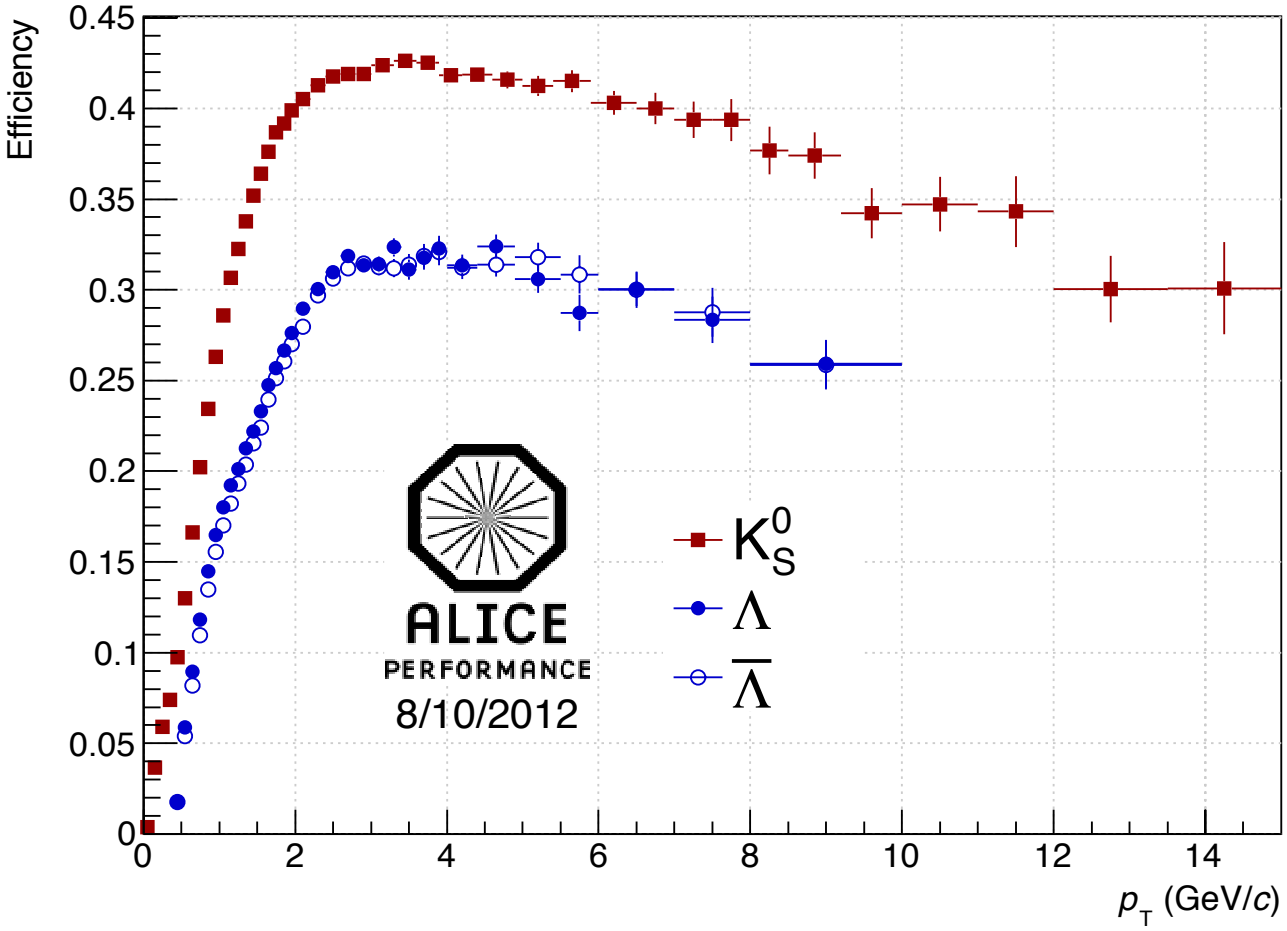
Total Feeddown Subtraction Fraction Example
(proton-proton @ 7 TeV)



~10% total removal for each Ξ species

Efficiency Corrections

Example: proton-proton collisions, √s = 7 TeV



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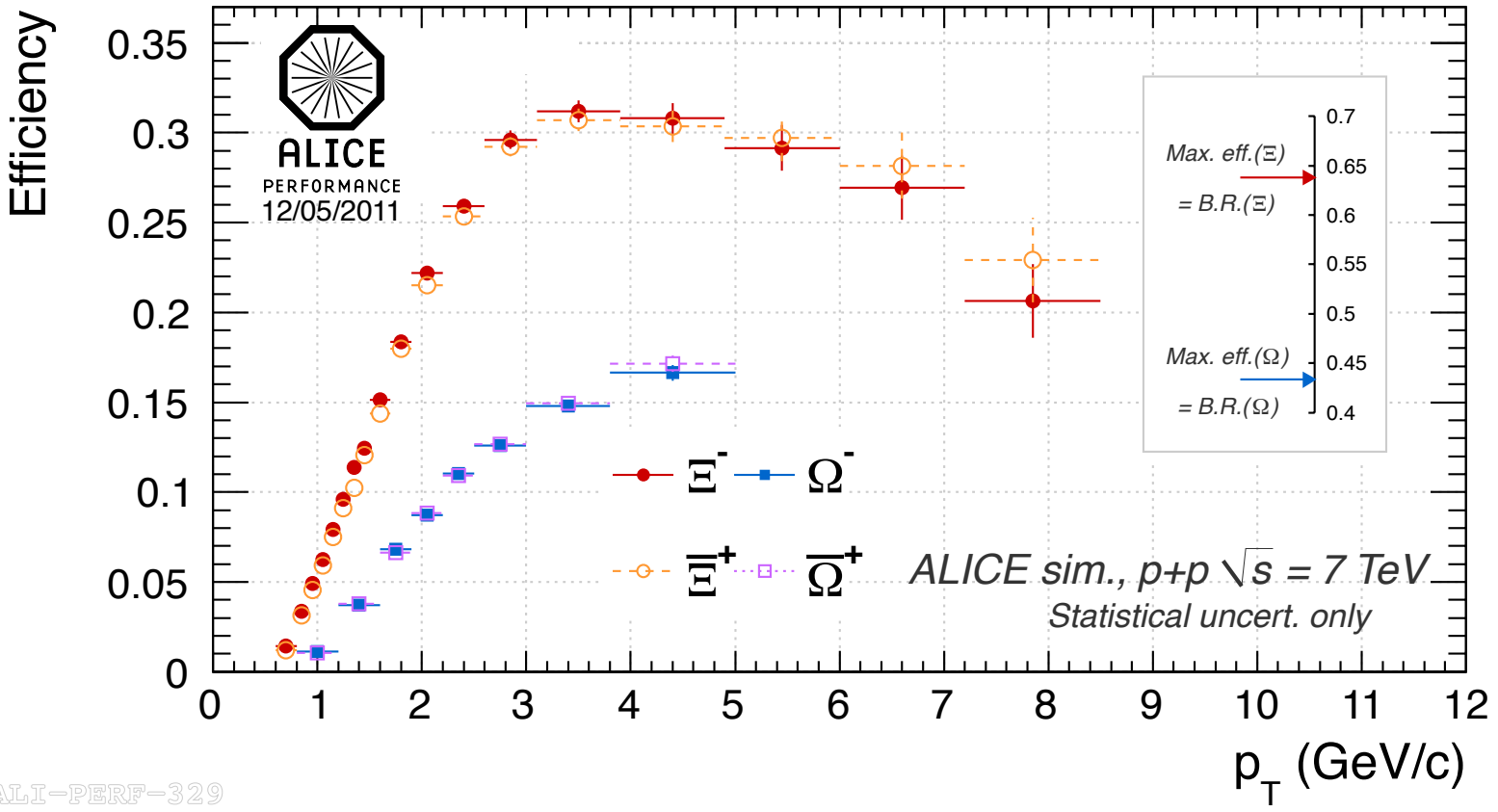
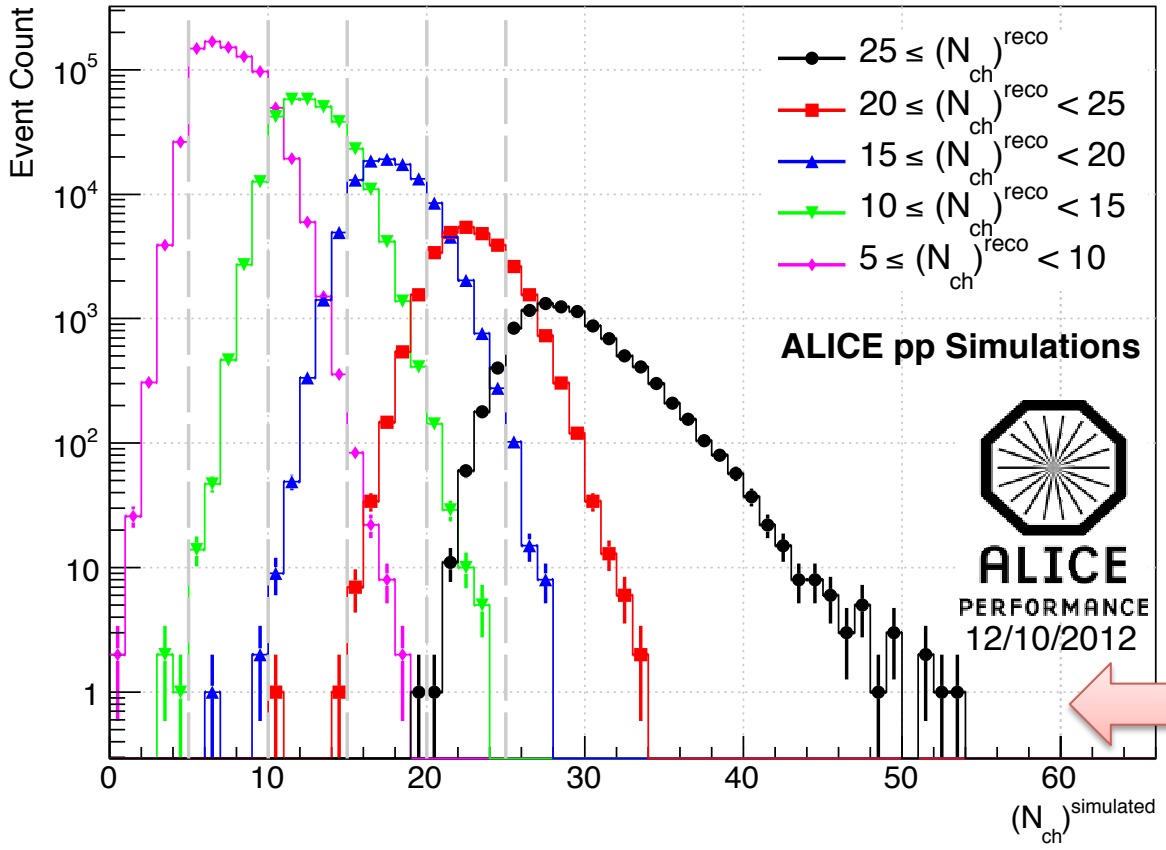


ALI-PERF-329

Proton-Proton at 7 TeV

Multiplicity: The next step?

Selection in: Reconstructed Charged Particles at mid-pseudorapidity, $(N_{ch})^{reco}$; desired: true $(N_{ch})^{simulated}$



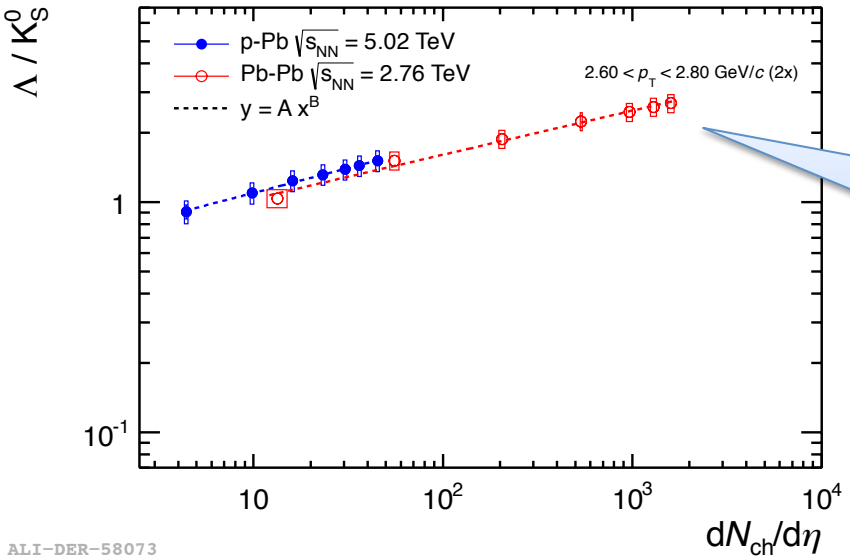
Interesting Physics:
Look at strangeness production according to charged particle multiplicity, **Compare to Pb-Pb**

May reveal more about hadrochemistry, production mechanisms…

Significant overlap between multiplicity bins

- *Unfolding needed*
- *Work in progress*

Multiplicity Scaling:
Λ/K^0_s at a given p_T as function of N_{ch}



Let's look at the ratio at a single pT value and see how it behaves with $dN_{ch}/d\eta$

Example: 2.6 – 2.8 GeV/c

- At this p_T, Λ/K0s increases with charged particle multiplicity

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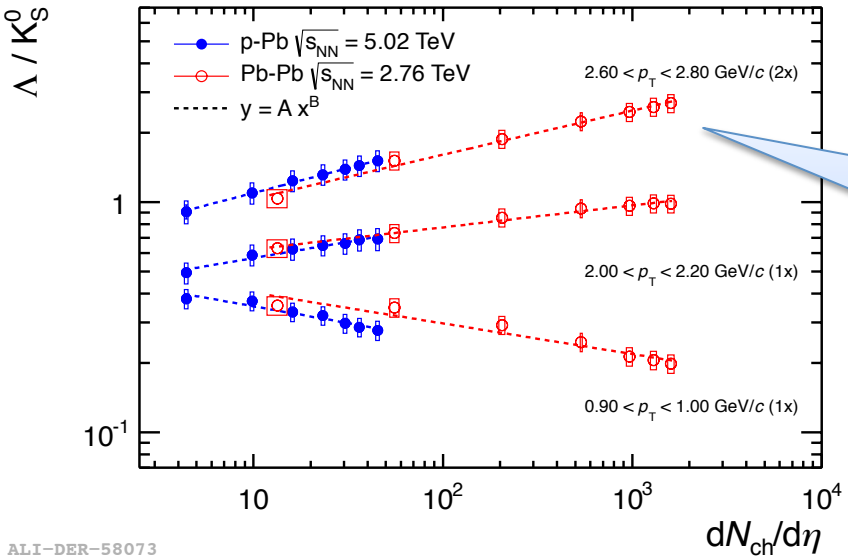

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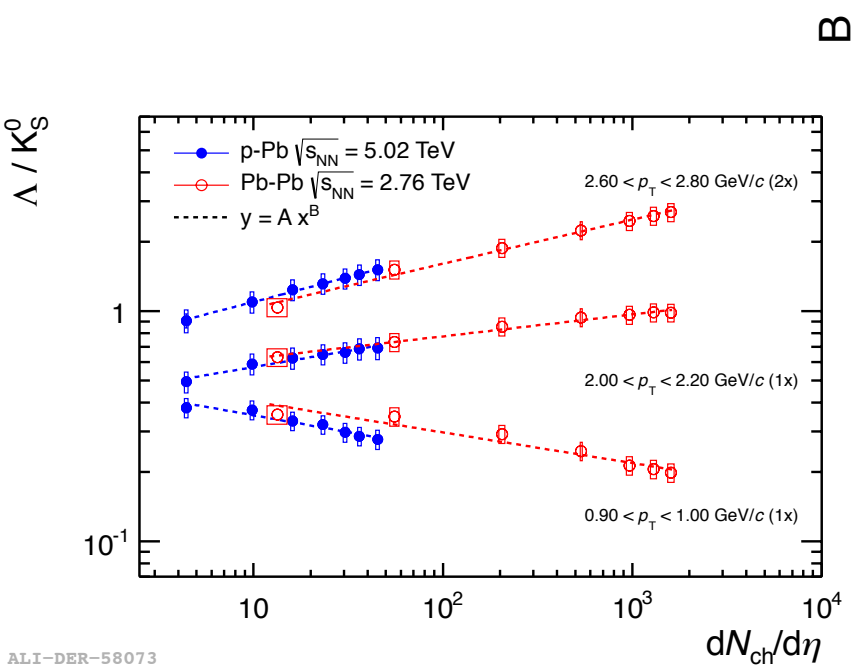
Example: 2.6 – 2.8 GeV/c

- At this p_T, Λ/K0s increases with charged particle multiplicity

As we look at different momenta, similar behaviour with $dN_{ch}/d\eta$ is observed in p-Pb and Pb-Pb: **similar change in ratio for a given change in $dN_{ch}/d\eta$**

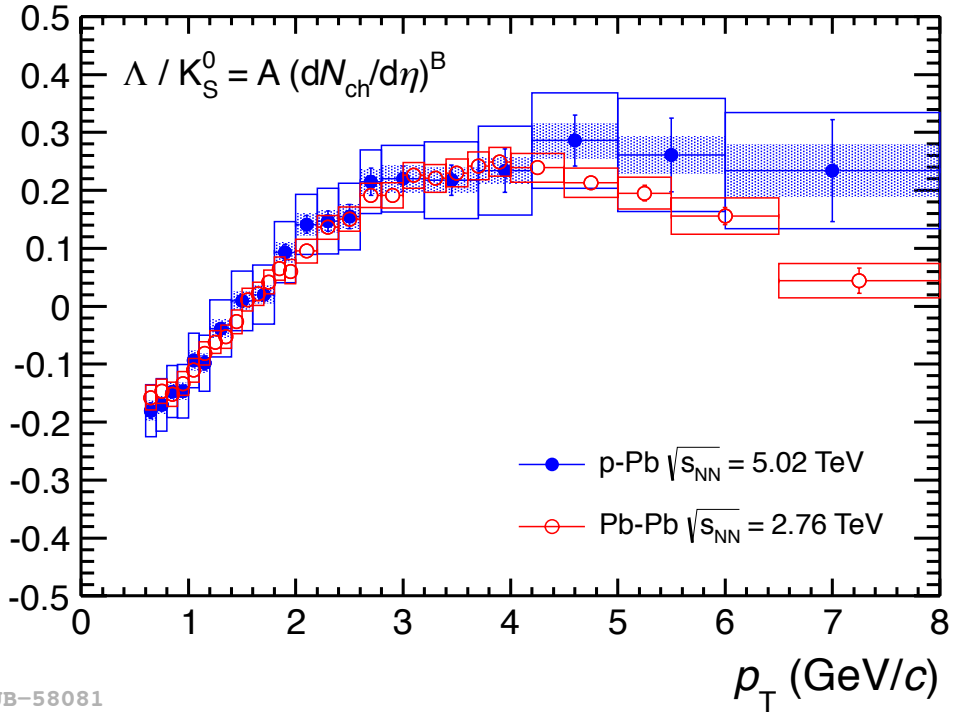
Multiplicity Scaling:

Λ/K^0_s at a given p_T as function of N_{ch}



ALI-DER-58073

B

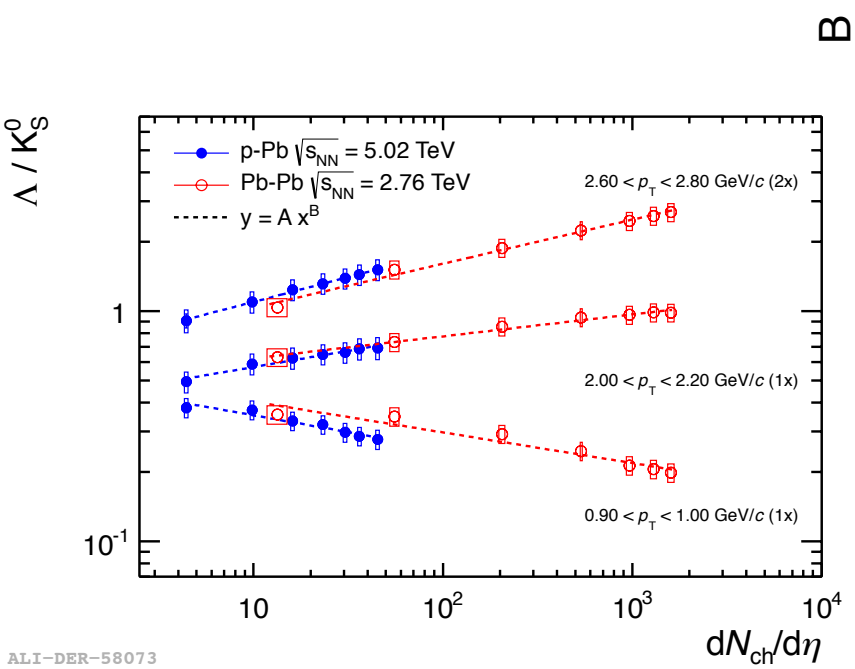


ALI-PUB-58081

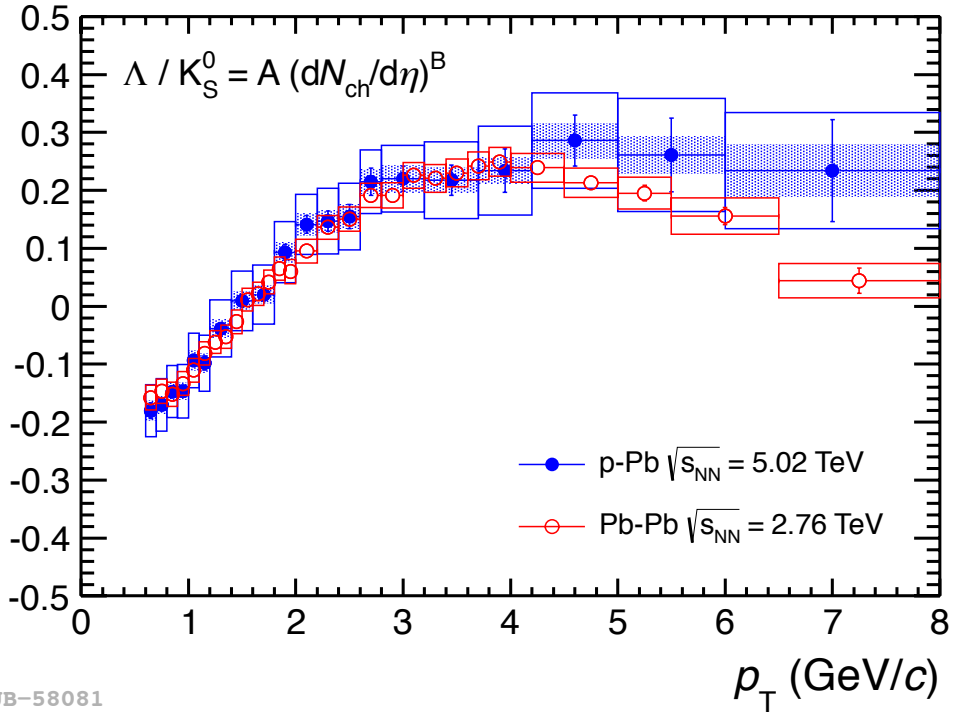
Fitting the ratio with a power law dependent on **$dN_{ch}/d\eta$**

Multiplicity Scaling:

Λ/K^0_s at a given p_T as function of N_{ch}



ALI-DER-58073

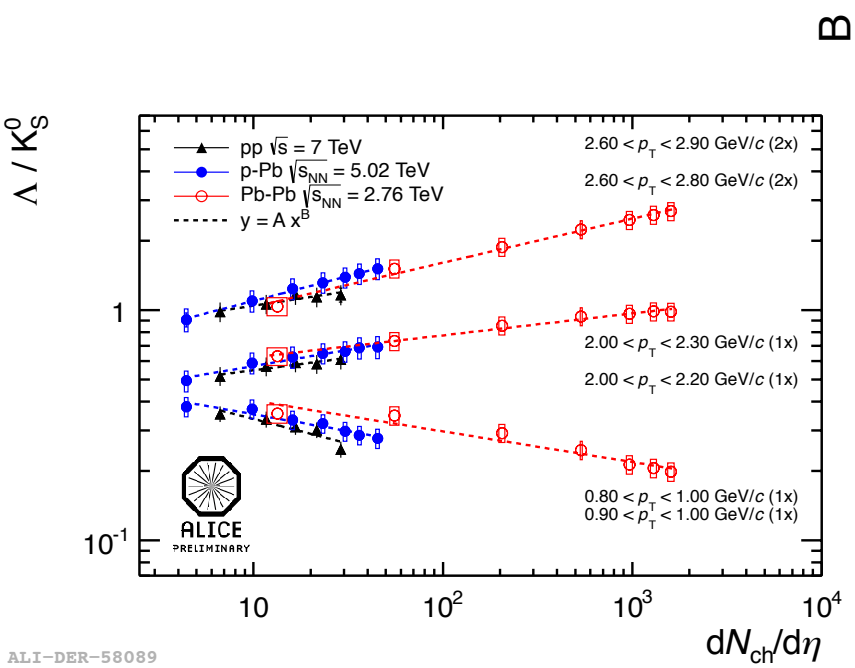


ALI-PUB-58081

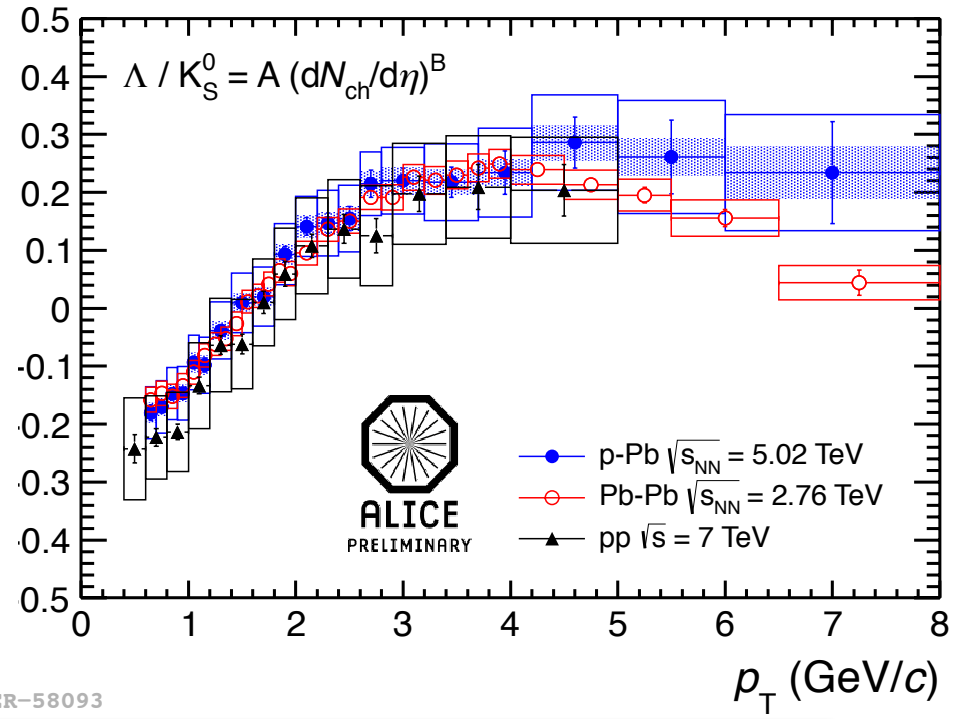
Fitting the ratio with a power law dependent on **$dN_{ch}/d\eta$**

What about proton-proton collisions as a function of **$dN_{ch}/d\eta$?**

Multiplicity Scaling:
…also with proton-proton data!



ALI-DER-58089



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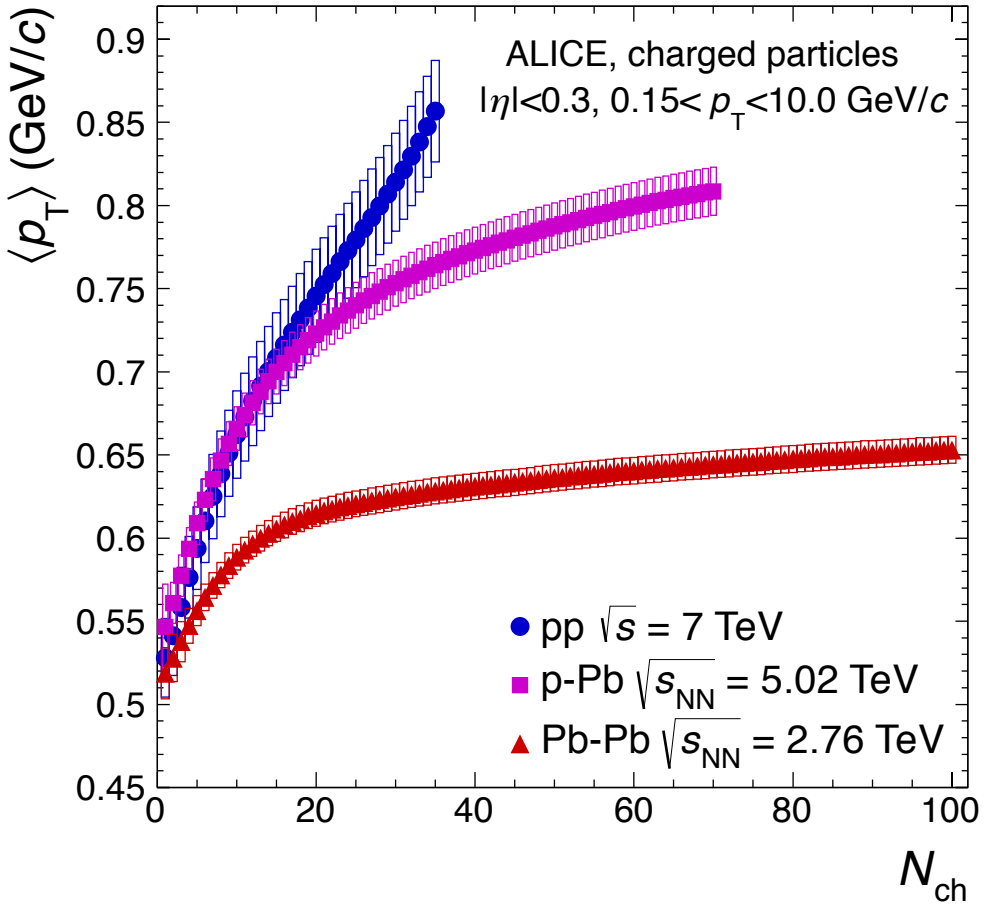
- Proton-proton systems **exhibit the same power laws** for the ratio as a function of **$dN_{ch}/d\eta$**
- **Caveat**: Λ/K^0_s ratio in pp collisions may be particularly sensitive to selection biases, since $dN_{ch}/d\eta$ measured at mid-rapidity

Published:

Progression of the average transverse momentum with multiplicity in different systems

http://arxiv.org/abs/1307.1094



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